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BULLETIN 350

GEOLOGY
OF THE
RANGELY OIL DISTRICT
RIO BLANCO COUNTY, COLORADO

WITH A SECTION ON THE WATER SUPPLY

BY

HOYT S. GALE

WASHINGTON
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GEOLOGY OF THE RANGELY OIL DISTRICT, RIO BLANCO COUNTY, COLORADO, WITH A SECTION ON THE WATER SUPPLY.

By Hoyt S. Gale.

INTRODUCTION.

LOCATION OF THE FIELD.

The Rangely oil field is situated in Raven Park, in the extreme northwestern part of Rio Blanco County, Colo. It lies a short distance north of the Colorado base line, which is approximately the fortieth parallel, and 10 to 15 miles east of the Colorado-Utah line. (See fig. 1.) The field occupies a basin which is a broadened portion

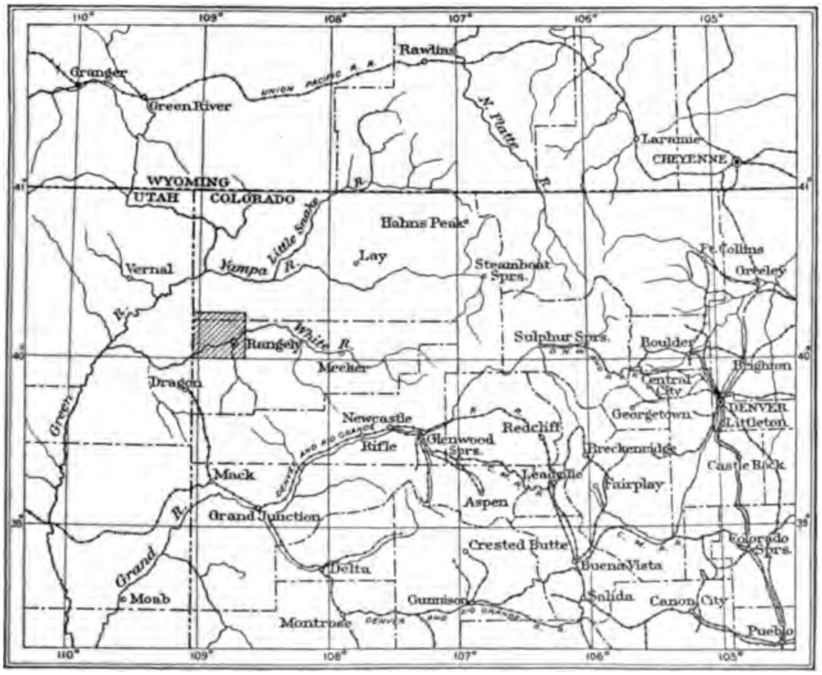

Fig. 1.—Index map showing location of Rangely oil district.

of the lower White River valley. It is included within the block of townships 1, 2, and 3 north of the base line in ranges 101, 102, and 103 west of the sixth principal meridian. Rangely post-office, from which the oil field takes its name, is the center of the scattering settlement along the immediate valley of the river, which skirts the southern margin of the basin. The post-office is about 33 miles from Dragon, Utah, the present terminus of the Uintah Railway. The trip from Dragon to Rangely can be readily accomplished in a single day, but must now (summer, 1907) be made by private conveyance, as no regular means of transportation is provided. Stage and principal mail connections from Rangely are by way of Meeker, the county seat of Rio Blanco County, which is 60 miles distant by road up the White River valley. A stage runs from Meeker to Rifle, a station on the Denver and Rio Grande Railroad, about 45 miles farther on. The whole trip from Rangely to the railroad by way of Meeker occupies about two and one-half days of actual travel, not including probable delays incident to the stage connections.

SCOPE OF THE PRESENT REPORT.

Present interest in the Rangely district centers mainly in its prospective development as an oil field. The intelligent study and exploitation of its oil resources must of necessity be based primarily on a knowledge of its geologic structure and rock formations. The field has already been described in the reports of the early geologic exploration of this general territory. The keen observation and admirable descriptions of C. A. White, who as geologist of the Hayden Survey studied this district in the early seventies, have appealed strongly to the popular understanding and have gained ready acceptance as a basis for the interpretation of many later problems of the field.

The present report is intended as a review of the geology of the field in greater detail than was possible in the early exploration and reports. It is also the purpose herein to discuss the conclusions reached in that earlier work and to correct some misinterpretations which are now widespread and probably originated there. The extension of detailed geologic study in Cretaceous and Tertiary strata of the Rocky Mountain and Plateau provinces in the last few years by various field parties of the Geological Survey has made available much additional evidence bearing on the general problems of the geologic history of these regions.

The maps (Pls. I, II, in pocket) are new and more accurate and detailed than any hitherto available. The structure sections (Pl. III, p. 34), though necessarily based largely on theoretical assumptions, are nevertheless carefully worked out from all the evidence available and are thought to be good representations of the relative thicknesses and structure of the stratigraphic formations that underlie this district.

It is hoped that the description and discussion given herein may prove to be of practical value in the economic development of the field. It is beyond the scope of this paper to make any specific predictions as to sites or possible productiveness of wells. The chief purpose, as suggested by the title of the paper, is to present a study and discussion of the geology of the district in which the oil has been found.

FIELD WORK.

The field work which forms the basis of this report occupied a period of about one month in August, 1907. The primary object of the work in this region was an investigation of the coal fields in this part of the State, for the purpose of determining their probable extent and value and of making a classification of the public lands. The topographic and geologic mapping is the work of John Allen Davis, Charles W. Stoops, and the writer.

TOPOGRAPHIC MAP.

The topographic map (Pl. I) which accompanies this report and serves as a base for the geologic mapping is a part of a larger map now (December, 1907) in course of preparation, intended for publication in a report on the coal fields of this general region. The amount and character of the surface relief of the region are represented by contours, or lines of equal elevation, spaced at vertical intervals of 100 feet. These were drawn in the field and to a large extent the sketching was done from the land-survey lines and corners. All the section corners that were found are shown by a symbol on the map, so that some estimate may be made of the relative accuracy of the sketching and locations by noting the corners and lines from which the information was obtained. In addition to the sketching and retracing of section lines, a number of the main roads of the district were traversed with plane table, this work being tied to land-survey corners, with intersections and angles of elevation recorded to prominent points for control.

The recently completed resurveys of the land subdivision lines were found to be in most satisfactory condition, so far as they could be checked by the methods employed during the present work. Most of the corners along the lines traversed were readily found and fairly well marked. It is to be regretted, however, that some of the monuments or corner stakes and markings are not of a more durable character and in a more permanent form. The well-established lines of this new land survey formed an excellent base for the horizontal control of the map here presented. These lines have been plotted according to the standard polyconic projection, with due allowance for convergence and curvature for the scale adopted at the given latitude.

The Colorado base line is approximately the fortieth parallel. The latest survey of this base line is a reestablishment of the older surveyed line, replacing the old corners by the present ones, which are set at 1-mile intervals according to the last and presumably most correct measurements.

Elevations shown on the map are based on and corrected to two lines of railroad surveys and levels, which traverse the Rangely district from east to west, one extending down White River and the other crossing by way of the longitudinal valley at the southern foot of Blue Mountain.[a] In order to record these data the alignments are shown on the map, together with the elevations given at various points along them. With future and more carefully adjusted work it will doubtless be found necessary to apply some minor corrections to the elevations that are given here, but in view of the somewhat incomplete connections with any well-established datum that are now obtainable no attempt has been made to revise the figures of the original survey. The following checks are obtained at the points named, which are independent and situated at either end of the line used:

Elevations at Newcastle, Colo., and Green River, Utah.

	Colorado Midland Railway survey via White River.	Denver and Rio Grande Railroad levels.[a]	Denver, Northwestern and Pacific (Moffat) Railway survey, corrected to Denver.	Evident correction.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Newcastle	5,570	5,552		−18
Green River, Utah, mouth of Ashley Creek, water levels	4,728		[b] 4,715	−13

[a] Gannett, Henry, Dictionary of altitudes in United States, 4th ed.: Bull. U. S. Geol. Survey, No. 274, 1906.

[b] Approximate.

The sketching of topography throughout the rest of the field is based on elevations determined by aneroid barometers.

GENERAL DESCRIPTION.

LOCALITY NAMES AND SETTLEMENT.

The Rangely Basin was first called Raven Park by C. A. White, who as geologist of the Hayden Survey visited the region in 1875. As a topographic basin it presents a curious contrast to the surrounding broken and more rugged country. The district as an oil field is now more generally known as the Rangely Basin, from the post-office located there. White defines the term "park" in the introduction to his report,[a] and according to that definition his use of the term to describe the White River valley at Rangely is correct. According to popular usage in the Rocky Mountain region, however, the term perhaps implies somewhat of the picturesque quality, a park being an open glade or valley surrounded or partly inclosed by timbered hills. With such a meaning the term would hardly be appropriately applied to the Rangely Basin. This basin is in truth a desolate waste of dry washes and almost barren clay ridges, except only the immediate valley bottoms of White River. There is probably but little change since the time of the Hayden Survey, beyond the establishment of scattering ranches along the river flats. A few wagon trails and wood and coal roads lead out over the ridges or among the well-drillers' camps and these, with an idle derrick or two and well-drillers' cabins, are the only present signs of habitation.

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[a] Routes were surveyed through the Raven Park district in December, 1886, and January, 1887, also in July, 1887, by the Colorado Midland Railway, to whose courtesy the writer is indebted for the use of the survey notes. Acknowledgment is also due to Mr. F. F. Mallon, of Colorado City, Colo., for his kindness and assistance in looking up these old records.

OUTLINE OF THE BASIN.

The Rangely Basin is irregularly oval in outline, its longer diameter extending from northeast to southwest with a total length of about 15 miles. The low valley portion, or Raven Park, has an approximate width of about 5 miles. The valley itself is bordered by an escarpment rim, averaging about 500 feet in height, which presents a steep scarp or cliff facing inward toward the basin center. This innermost escarpment edge is locally known as the "rim rock" and is easily recognized as the upper limit or cap rock of the oil-bearing shale, from which the park has been eroded. Beyond the "rim rock" the ridges dip away in more gradual slopes, rising in successive steps upon cliffs of the higher sandstone strata. Higher steep escarpment bluffs above and beyond the "rim rock" face inward in concentric arrangement rudely parallel to the margin of the park. Sharp rocky canyons intersect the surrounding ridges, draining into the central valley.

DRAINAGE.

White River enters the park through a canyon at its southeast extremity, flows along the southern margin, and leaves again by another canyon. Below the park the river flows continuously in a deepening canyon for the remainder of its course in Colorado. Raven Park thus lies for the most part north of the river valley. Besides the river itself one perennial stream enters the park from the south. This is Douglas Creek, which drains an extensive area south of White River. Its headwaters reach back to the divide between White and Grand rivers along the summit of the Roan or Book Cliffs Plateau. North of

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[a] Report on geology of a portion of northwestern Colorado: Tenth Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1878, pp. 9.

White River the principal drainage is a wet-weather stream known as Stinking Creek, originally named Unga-too-roosh on the Hayden maps. This, like most of the other drainage channels of the region, is dry most of the summer except immediately after heavy showers, when it runs full with thick muddy water for a few hours only. All these waters are heavily charged with alkaline salts.

SURFACE AND VEGETATION.

The dry, hard soil supports but little vegetation. The clay ridges are sparsely covered with the interminable sage, greasewood, and prickly pear. Along the immediate channels of the dry washes the same shrubs are found in thicker growth. The ground absorbs but little water even after the occasional floods of the summer storms. In heavy showers the water barely wets the top of the ground, running off rapidly and leaving the surface to harden again and crack in the dry air. Lack of water supply, absence of feed for cattle or horses, and the general destitute character of the region as a whole had caused but little value to be attached to the land until the existence of oil was discovered seven or eight years ago.

ROCK FORMATIONS.

GENERAL SUMMARY.

The rocks exposed in the vicinity of the Rangely field represent a large interval in the geologic time scale. On the great axes of uplift that form a part of the Uinta Mountain system north and northwest of Raven Park erosion has exposed the oldest rocks that occur in the region. On the southern flanks of Blue Mountain rocks as low as Carboniferous are brought to view, and from Blue Mountain southward a thickness of more than 7,500 feet of tilted Mesozoic strata is exposed in detail. These beds overlie the incompletely exposed section of Paleozoic rocks and in turn are covered by a similar thickness of Tertiary strata toward the south. The following list of formations and periods is given to outline the groups into which these strata are subdivided for purposes of description:

Summary of formations exposed in the Rangely district as represented on the geologic map (Pl. II, in pocket).

Period.	Formation.	Derivation of the formation names.
Tertiary	Green River	King, Powell, and Hayden reports.
	Wasatch	
	(Unconformity.)	
Cretaceous	Mesaverde formation	Cross, southwestern Colorado reports.
	Mancos shale	
	Dakota sandstone	Meek and Hayden and others.
Jurassic	"Flaming Gorge"	Powell, Geology of Uinta Mountains.
	"White Cliff"	

A discussion of the occurrence of the Rangely oil is directly concerned only with the Cretaceous formations of the preceding table.

For this reason the descriptions here given are largely confined to these formations and include only brief mention of such strata above and below as naturally fall within the field included by the geologic map. It is the intention of the author to present a fuller discussion of the more complete stratigraphic section in a later paper.[a]

PRE-CRETACEOUS ROCKS.

Immediately below the Dakota sandstone is a mass of variegated badland-forming shale and clay, including some harder beds of limestone and sandstone, together with a peculiar dark cherty, siliceous conglomerate almost exactly like that commonly found with the Dakota formation above. The shale or marl is prevailingly of greenish and pinkish shades, with some beds that weather yellow. The lower 100 to 150 feet of this formation is composed of darker-colored beds, fine greenish sandstone and calcareous rock. Limestone layers composed largely of shells are present near the base, although the general character of the beds seems to indicate much limy or marly material throughout. These beds have an approximate thickness of 800 feet, as measured near the base of Blue Mountain. They are well represented in the excellent exposures on the steep northern slopes of the Dakota hogback in that locality, the more resistant sandstones of the Dakota formation capping and preserving from erosion the upper members of these weaker beds. The lower beds almost invariably form valleys, and as they are usually tilted at considerable angles, their outcrop is a relatively narrow strip between inclosing ridges. The lower strata of these variegated beds are of marine origin, as shown by the fossils they contain; the upper part, by analogy with other and better-known sections, is supposed to be composed largely of fresh-water deposits.

The variegated and shaly beds are limited at the base by a second group of sandstones which, like the Dakota, usually forms a steep rocky ridge. This group is more completely composed of sandstone than the Dakota, and is even more conspicuous as a ridge maker. It is usually very white and massive and cross-bedded to an extreme degree.

The variegated beds are of Jurassic age and probably correspond in their upper or supposedly fresh-water part to the Morrison formation east of the Rocky Mountains. They have also been variously named "Flaming Gorge," McElmo, and in part Gunnison in the Uinta Mountain and western Rocky Mountain regions. The relations of these formations are indicated in the correlation table on page 27. The cross-bedded white sandstone is also of Jurassic age, as is shown by fossils obtained from this field. It is with little doubt the equivalent of the " White Cliff " sandstone mapped by Powell on the north side of the Uinta Mountains, and also seems to be with almost equal certainty equivalent to the La Plata sandstone[a] of the southwestern Colorado sections. The following fossils were collected from these formations during the last season, and are considered to prove conclusively the Jurassic age of the beds in which they were found. All are of marine types, being from the basal portion of the variegated beds and from the upper half of the cross-bedded white sandstone.

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[a] Coal fields of northwestern Colorado and northeastern Utah: Bull. U. S. Geol. Survey (in preparation).

Fossils collected from the Jurassic rocks north of Raven Park.[b]

- Variegated beds:
  - Ostrea sp.
  - Ostrea strigilecula White.
  - Eumicrotis curta (Hall).
  - Tancredia (?) inornata Whitfield.
  - Astarte sp.
  - Belemnites densus M. and H.
- Cross-bedded white sandstone:
  - Trigonia quadrangularis H. and M.
  - Tancredia sp.

The principal economic interest that has as yet been attached to these beds is due to the occurrence of deposits of ores of uranium and vanadium in the massive cross-bedded sandstone. These deposits have been elsewhere described.[c] A single observed occurrence of a bed of hard black carbonaceous material which is probably an impure coal has been found in Red Wash Creek where its channel cuts the ledges of cross-bedded Jurassic sandstone, the bed outcropping among the upper members of that formation. The coal is 2 to 3 inches thick and only slightly weathered, occurring at water level in the rather badly disintegrated sandstone. Although very poorly exposed, it is apparently interstratified with the sandstone itself. The analysis of this material has given the following results:[d]

Contains less than 1 per cent of matter soluble in carbon disulphid and does not soften in flame; therefore is not gilsonite or related hydrocarbon. As a coal it has approximately the following composition:

Analysis of coal from Red Wash Creek.

Moisture	10.5
Volatile matter	42.9
Fixed carbon	42.0
Ash	4.6
	100.0

---

[a] Cross, Whitman. Stratigraphic results of a reconnaissance in western Colorado and Utah: Jour. Geology, vol. 15, 1907, p. 642.

[b] Determinations by Dr. T. W. Stanton; collections now in United States National Museum.

[c] Contributions to Economic Geology, 1907: Bull. U. S. Geol. Survey No. 340, 1908, pp. 257-262.

[d] Analysis No. 2282 by E. C. Sullivan, in the chemical laboratory of the United States Geol. Survey.

DAKOTA SANDSTONE.

The Dakota sandstone does not come to the surface in Raven Park, but is well exposed in the foothill ridges at the southern edge of Blue Mountain, a few miles farther north. This formation lies at the base of the oil-bearing shale and has been supposed by many interested in the development of this field to offer highly favorable conditions for the storage of large bodies of oil. It has thus been the objective point for most of the deeper wells drilled in this field.

The remarkable persistence of its lithologic character and its continuity of exposure over such extensive areas have led to the acceptance of the Dakota sandstone as a key rock for the correlation of widely distributed stratigraphic sections of the Mesozoic rocks, both above and below that horizon. Few fossils have been obtained from it in the territory adjacent to the Rangely field, and its recognition there is based on tracing from other fields, on its position immediately below the abundantly fossiliferous lower Mancos (Benton) shale, and on the lithologic constitution of its beds, which correspond to those widely accepted as characteristic of the Dakota.

Although the details of the formation exposed at the southern foot of Blue Mountain can hardly be expected to correspond precisely to those of the formation as it lies underneath the Rangely field, a description of the Blue Mountain section contains the best available estimate of the character and thickness of these beds than can now be had. The following measurements were made of the tilted strata exposed near the headwaters of Willow Creek, one of the principal tributaries of Stinking Creek, in the NW. ¼ SE. ¼ sec. 12, T. 3 N., R. 103 W.

Section of Dakota sandstone at Willow Creek.

	Feet.
1. Sandstone, weathered brown (overlain by dark-gray and black slaty shale, supposed to represent the base of the Mancos [Benton])	10
2. Shale with beds of white clay and a hard siliceous conglomerate: shale very black and slaty near its base	110
3. Sandstone, white, cross-bedded, containing conglomerate layers	40
4. Interval, probably shale, covered by sandstone slide-rock	180
5. Sandstone	3
6. Shale, variegated in colors of pink and green, containing also one or more beds of dense reddish-purple limestone	95
7. Conglomerate, of coarse, perfectly rounded pebbles in a scant sandy matrix: pebbles largely of chert and siliceous material	45
	483

Doctor Stanton has expressed the opinion that Nos. 4 to 7 of the Willow Creek section as indicated above may be found to be older than the Dakota. He says "the variegated shale (No. 6) suggests the Morrison or possibly the Fuson of Darton's Black Hills section." If this opinion is correct the massive conglomerate stratum so naturally included in the base of the Dakota may really be a part of the underlying Jurassic formations and not Dakota at all. This view is given only as a tentative suggestion.

The Dakota outcrop extends westward from the Willow Creek locality continuously, with much uniformity in character and thickness, to and beyond the Colorado-Utah boundary. It there forms a steep, rocky ridge whose summit is composed of the heavy basal stratum of coarse conglomerate, resting immediately upon the variegated clay of the underlying Jurassic. East of the Willow Creek locality the coarse basal conglomerate is found as far as Red Wash Creek, beyond which it is thin or wanting entirely. Near Three Springs, about 15 miles east of Willow Creek, the whole Dakota formation is thin, being apparently represented by an outcrop of two inconspicuous sandstone beds, each not over 10 feet in thickness, separated by an interval of shale.

The only fossils that were found in these beds consist of a few very indistinctly preserved leaves. These were collected in a prospect pit exposing a black carbonaceous shale included between the massive white sandstones near the top of the formation. The pit is situated in the SE. ¼ sec. 5, T. 3 N., R. 101 W., just north of the Yampa River and Vernal wagon trail and near the headwaters of the west fork of Red Wash Gulch. The specimens collected could not be identified, but the locality may serve as a guide in further search for better material.

MANCOS SHALE.

The formation next above the Dakota is the Mancos shale, a thick mass of homogeneous clay shale with a few more sandy layers. It is considered here as a single unit, although it has formerly been subdivided into various formations, largely on paleontologic grounds. The relation of the Mancos shale to the subdivisions of the earlier explorers is indicated in the correlation table on page 27. From this it may be seen that Mancos includes all that has been previously termed Colorado and also a part of that classed as Fox Hills by White, of the Hayden Survey. It thus includes also the Benton, Niobrara, and a part of the Pierre formations, according to a classification of the Cretaceous section based on subdivisions originally adopted for strata of the upper Missouri River and adjoining fields. In brief, the Mancos is intended to include all of the predominatingly shaly strata above the Dakota and below the massive sandstones of the next succeeding or Mesaverde formation.

Raven Park is eroded on the Mancos shale, and it is in this formation that the oil of the Rangely field has been found. The least-altered exposures of these beds known in this area are those found in the bluffs along the north side of White River. Here the shale occurs in slightly weathered condition and presents a more compact, slaty appearance than is usual for this formation. Where fresh and undisturbed the shale is dark and fine grained, and in part at least shows thin lamination with considerable cross jointing. As more commonly exposed in escarpment bluffs or in wash banks of the many intermittent drainage channels, it dries to a lighter-gray color, blending with that of the soil into which it so readily breaks down. By reason of its nonresistant nature this formation commonly gives way to a heavy clay soil cover over low, rounded slopes, and is rarely exposed in a fresh condition.

The basal part of the Mancos shale may be naturally and readily distinguished as a distinct division of the formation, and contains Benton fossils. The Dakota sandstone is almost invariably overlain immediately by 200 feet or more of dense black slaty shale, which usually forms a long, low valley on the dip-slope side of the Dakota ridge. Above these beds is a similar thickness of shaly strata containing a number of more resistant beds of sandstone and limestone, which usually give rise to a distinct line of minor hogbacks similar to those of the Dakota, though of lesser elevation and more largely composed of shaly strata. The sandy layers are in many places of dark color and of moderately fine and even grain, and are as a rule flaggy or somewhat thinly bedded. These beds are commonly fossiliferous, and the calcareous beds also contain abundant shells. Collections obtained from many localities assign these rocks definitely to the upper part of the Benton shale.[a] The following is a list of identified species from the Willow Creek section described above:

Benton fossils from Willow Creek at the southern foot of Blue Mountain.

Ostrea lugubris Conrad.
Inoceramus fragilis H. and M.
Inoceramus dimidius White.
Scaphites warreni M. and H.
Prionocyclus sp.

---

[a] Determinations by Dr. T. W. Stanton; collections now in United States National Museum.

Above the sandstones the remainder of this great shale formation attains a thickness of approximately 5,000 feet, or about 1 mile. It is to all appearances of homogeneous composition throughout, but the records of oil wells driven through it distinguish layers described by some of the drillers as sandy.

The uppermost part of the Mancos shale is perhaps more commonly exhibited at outcrops than any other part of the formation, with the exception of the lowest few hundred feet already described. By reason of the protection offered by the lowest sandstone layers of the next succeeding formation, it occupies in many places nearly the whole face of the escarpment up to heights of 600 or 800 feet. Of these topmost beds the lower portion is normally buried in the débris that slides down from the steep slopes above. The shale here appears to be lighter in color and more sandy than the basal beds already described, but it is uncertain whether this is the result of long exposure to weather and the consequent drying out of its natural moisture, or to variation of constitution in the upper part of the formation.

The soil that forms upon the surface of the Mancos shale is a compact clay, very hard when dry but becoming a deep plastic mud when thoroughly wet. This soil is usually hard and dry during the summer, when its surface becomes deeply cracked and fissured. Rains of short duration, such as frequently occur in the summer season, scarcely penetrate the soil at all, except as they fill these cracks. Surface water runs off rapidly, cutting abrupt vertical-sided channels or miniature canyons even to a depth of 50 feet or more. These gullies rapidly extend and deepen with each succeeding flood, and in places the dissection becomes so intricate as to produce a typical badland. Areas of such topography, which characterizes much of Raven Park, are accessible only with much difficulty, and then only by avoiding the stream courses as far as possible and following the dividing ridges.

The soil is in many places filled or covered with scattered fragments of selenite, which is gypsum in its clear, crystalline form, and larger pieces of this mineral are strewn about upon the surface, as if residual in the soil from the disintegration and removal of the original shale.

The fossils that have been found in the Mancos shale were obtained mainly near the base (see list of Benton fossils, p. 15) and from the upper layers near the base of the next succeeding formation. The fossils from these upper layers are of marine types, which were formerly considered as characteristic of a so-called Fox Hills fauna, and the beds were included by White in his formation of that name. The following is a list of species obtained during the work of the last season from localities in and adjacent to Raven Park:

Fossils from upper part of Mancos shale in White River valley.[a]

Serpula sp.
Ostrea sp.
Syncyclonema rigida H. and M.
Avicula nebrascana E. and S.
Inoceramus sagensis Owen.
Inoceramus cripsi var. barabini Morton.
Mytilus subarcuatus M. and H.
Sphæriola? cordata M. and H.
Cardium speciosum M. and H.
Lucina sp.
Legumen sp.
Leptosolen sp.
Anatina sp.
Goniomya americana M. and H.
Liopistha undata M. and H.
Pholadomya sp.
Spironema? sp.
Odontobasis sp.
Cinulia sp.
Anisomyon sp.
Baculites compressus Say.

The thickness of the Mancos shale is a fundamental consideration in determining the depth to which wells must be sunk in the Rangely field in order to reach the Dakota sandstone. As a large part of the drilling has been carried on with this specific purpose in view the question of that thickness has received much attention from the drillers. When prospecting in the field was first started, White's estimates, given in the Hayden report, were accepted apparently without question. White gave the thickness of the "Colorado" formation as 2,000 feet in the upper White River valley, near Agency Park, but also stated that it was much thinner toward the west, in the vicinity of Raven Park. The first drilling in the Rangely field, however, showed that the figures given in that report were too small. Various attempts were then made to get more accurate information on this subject, but most of them were not very successful. For this reason the thickness of the formation is fully discussed here, and the evidence on which the conclusions are based is given in considerable detail.

The thickness of the Mancos shale may be determined from its upturned edge exposed along the southern foot of Blue Mountain, where these beds form a long, low valley parallel to and south of the Dakota ridge. Several estimates of this thickness have been made in recent years by those interested in drilling through the formation in the Rangely oil field. Most of such estimates have been made just east of the Willow Creek locality at which the detailed section of the Dakota formation (p. 13) was obtained. Chain measurements by Mr. C. F. Carney and others, of Meeker, are said to have shown the breadth of the Mancos Valley at this point to be 4,750 feet. The central portion of the valley is buried in alluvium; consequently the only dip measurements available on which to base an estimate of the true thickness of the shale are those shown in the rocky ridges along the valley margins at the north and south. These dips on the two sides of the valley do not accord, ranging from 33° to about 45° on the north, along the Dakota ridge, and increasing to angles of 75° and near verticality along the southern margin. Considerable uncertainty remains in the estimates of stratigraphic thicknesses based on the data given above, for if the beds are nearly vertical across the major portion of the valley, as they are at its southern margin, their thickness would be from 4,500 to 4,700 feet, but if the lighter dips at the north continue across the valley the thickness of strata represented is only about 3,000 feet. It may be concluded that the true thickness is somewhere between these two limits. The writer is inclined to believe, however, that no measurement obtained in this locality is reliable, and that the apparent regularity of the structure is misleading. As may be seen by reference to the geologic map (Pl. II) accompanying this report, the Dakota hogback bends rather abruptly at the point where Willow Creek emerges from it, about 800 feet east of the center of sec. 12, T. 3 N., R. 103 W. A general view of the topography in this vicinity clearly reveals also a corresponding bend in the structure of all the formations exposed. Thus the longitudinal valley which is eroded along the outcrop of the Mancos shale immediately south of and parallel to Blue Mountain bends abruptly across a zone which extends about due south from the site of the Willow Creek section. At the southern margin of the valley directly opposite the Willow Creek section (NE. ¼ SE. ¼ sec. 13, T. 3 N., R. 103 W.) the strata are irregular and apparently broken and this disturbance continues to the northeast for at least a quarter of a mile, the valley narrowing markedly in that direction. It is in this constricted portion of the valley that most of the measurements of the thickness of the Mancos shale have been made. The disturbance in this area is thought to have been produced by shearing movements within the mass of the shale, rather than by clearly defined faults. The irregular structure is evidently related to the narrowing or partial discontinuity of the Red Wash syncline, which extends eastward, broadening and deepening from this point, as is explained in the section on structure.

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[a] Determinations by Dr. T. W. Stanton; collections now in United States National Museum.

There are many places in the valley south of Blue Mountain where it seems fair to assume a uniform dip clear across the valley, but in most of these localities the greater part of each section is concealed beneath the valley wash. Calculations made from measurements at several such points indicate a minimum thickness of about 5,000 feet for the Mancos shale.

An estimate of the thickness of the Mancos shale can doubtless be obtained from well records, if the wells ever reach the Dakota in localities where an estimate of that part of the shale which has been eroded from the well site can also be obtained. The Union well in Raven Park, described on page 42, has been sunk to a depth of 3,655 feet in lightly dipping strata, so that this figure very closely approximates the true thickness of the beds passed through. About 1,200 feet of strata have been eroded from the site on which the well is located, this estimate being based on the same data which were used in constructing the cross section (Pl. III, section C–D) that passes through and includes the Union well. There is some evidence that the bottom of this well is about 300 feet above the Dakota sandstone. The total thickness thus obtained is slightly greater than 5,000 feet when corrected for the light dip of the strata, and this agrees very closely with the estimates made at the more favorable localities along Blue Mountain.

MESAVERDE FORMATION.

The uppermost and youngest strata of the Upper Cretaceous section in the Rangely district, as well as in the whole of the Grand River basin, are equivalent in age to the Mesaverde formation as mapped in the Yampa coal field.[a] These beds succeed and overlie the Mancos shale, from which they are distinguished chiefly by their generally more sandy character and the prominence of the massive sandstone ledges. As a whole this formation is composed of massive sandstones, interbedded with sandy shales and many beds of coal and carbonaceous shale. Of these rocks the sandstones are most conspicuous by reason of their greater resistance to erosion than that offered by the softer beds. The formation is thus typically represented by a more or less rugged country, characterized by escarpment ledges and cliffs. The massive sandstones are commonly of medium or rather coarse grained texture, locally showing some cross-bedding, although this is not a distinguishing feature. In many places they weather near the surface to a variety of shades, usually of reddish or yellowish color, which is probably the result of the oxidation of some iron constituents. Where these beds are exposed in mines or in freshly cut rock faces, they are commonly of clear white sand, firmly cemented when fresh, but they crumble and soften readily with exposure to the weather. Much of the cementing material in the sandstone is probably of calcareous or alkaline nature, as calcareous, magnesian, and ferruginous salts are almost invariably found in the waters that leach from these beds. Such salts commonly occur as efflorescent deposits in natural cavities in the massive sandstone, or under projecting ledges where sheltered from the solvent action of rain and snow water.

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[a] Fenneman, N. M., and Gale, H. S., The Yampa coal field, Routt County, Colo.: Bull. U. S. Geol. Survey No. 297, 1906, pp. 22–28.

In general the shales differ from those which constitute the main body of the Mancos, being usually of lighter color as well as more sandy. They show much variation in constitution, ranging from compact clay shale somewhat resembling the typical Mancos rock to sandy shale and from this to thin-bedded and flaggy sandstone. The coal beds constitute one of the most important economic resources of the region. The coals are bituminous and of a good grade, being similar to those of the Danforth Hills field, such as the coals near Meeker. As they are elsewhere[a] described in considerable detail, further discussion of them is omitted here.

As shown on the geologic map forming Pl. II (pocket), the lower part of the Mesaverde is distinguished as a separate member by a distinct pattern, the top boundary representing the base of the principal groups of workable coals. Within a small area such as the Rangely district certain parts of the Mesaverde formation are sufficiently continuous and characteristic to be distinguished and traced throughout the field, although they vary greatly in actual detail within very short distances. Perhaps the most conspicuously constant member of the whole formation as viewed from Raven Park is the irregularly oval escarpment surrounding the valley. This escarpment is composed of the lowest sandstone member of the formation, and is locally known as the "rim rock." The view given in Pl. IV, *A*, illustrates a characteristic portion of this member, and shows the underlying bluff of Mancos shale, capped and preserved by the hard sandstone ledge. The sandstone, or "rim rock" itself, is a bed ranging in general from 20 to 50 feet in thickness. Above this is a mass of characteristic sandy shale, 500 to 600 feet thick. These shales are, in general, easily eroded, leaving the outer edge and in many places a considerable portion of the back slope of the "rim rock" bare. Beyond the gentle back slope of the "rim rock" (as expressed in the contouring on the topographic map) a second characteristic escarpment rises above the first, capped likewise by a group of cliff forming sandstone beds. Of these the lowest is most commonly of a rusty brown color, resembling the weathered ledge of the "rim rock" below, and the third and fourth as commonly show a clear white aspect, in marked contrast to the group of darker ledges below. At about the horizon of the third sandstone above the base a thin bed of coal or dark carbonaceous shale is present at many places. This section is significant for purposes of correlation by comparison with the strikingly similar section near the base of the same part of the formation in Agency Park, north of Meeker, and also at many localities along the borders of Axial Basin. Above this second group of sandstones the members become less distinct as individuals, but merge into a prominent series of cliff-forming sandstones, continuing as such up to the horizon of the principal coal group already mentioned. Into these massive sandstones the steep rocky gorges and canyons of many intersecting streams are cut. This lower part of the formation is relatively barren of coal, but is prominent as a ridge maker. Its total thickness ranges from 1,000 to 1,500 feet. The measurements from which the larger estimate is obtained were made in Chase Gulch, northeast of Rangely.

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[a] Progress report on investigation of coal fields in northwestern Colorado and northeastern Utah. Bull. U. S. Geol. Survey No. 341, 1908.

The upper part of the Mesaverde formation is also distinguished as a separate member on the geologic map, the line which marks the lower limit of the principal group of workable coals representing its base. These upper strata resemble very closely the underlying beds, except that the predominance of the massive and resistant sandstone members is not so pronounced and the resulting topography is consequently not so rugged. One of the most readily distinguished horizons in the Mesaverde is the bottom of the principal workable coals. This general horizon has been traced continuously for at least 200 miles along the outcrop and, as already mentioned, is shown by a line on Pl. II. It is marked by a conspicuous white sandstone bed which is commonly one of the most massive members of the whole formation. In a large part of the Danforth Hills this bed is a very prominent white ledge. From its characteristic appearance it has come to be known in the vicinity of Axial post-office as the "white rock." As this member is traced west of that field it disappears and reappears intermittently, so that its position is locally a matter of some conjecture, even in a well-exposed section. Here, as in the Danforth Hills, wherever it can be recognized it furnishes a key rock by which to identify the more valuable coal beds that lie above it.

Above the "white rock" the sandstones and shales alternate in a variable succession, showing almost everywhere some signs of the coal beds that they include. The coals themselves are in many places made conspicuous by the burning which has taken place along their outcrops, baking the inclosing strata to brilliant shades of red and yellow and hardening the clay and shale to a flinty texture. Less commonly the coal beds are found in natural outcrop or show as black streaks along the hillside. By reason of the weaker character of this carbonaceous material it is usually broken down and concealed by the débris of the harder adjacent strata. From the "white rock" to the top of the formation, coals occur at irregular intervals, the principal beds being almost invariably concentrated near the base, or not far above the "white rock."

A number of carefully measured sections of the Mesaverde formation, taken along the Grand Hogback east of the Rangely district, have already been published in a description of the upper White River coal fields.[a] In that region the formation attains a thickness of somewhat over 5,000 feet, or approximately 1 mile. Opportunities for measurement near Raven Park are not so favorable, but the thickness of the Mesaverde here appears to be not more than half that which prevails in the Grand Hogback and Danforth Hills. The principal difficulty in obtaining a satisfactory measurement in the lower White River territory lies in the uncertainty regarding the upper limit of the formation. It is possible that during Mesaverde time a smaller amount of sediment was deposited in the Raven Park region than in the Danforth Hills and farther south. On the other hand, the greater thickness of the formation in the eastern part of the basin is probably to be explained by the assumption that most of the beds originally deposited there still remain, whereas in the western part a large amount had probably been eroded from the upper portion of the formation before the next succeeding strata were laid down. This explanation is more probable, because the section of the Mesaverde formation near Raven Park corresponds in grouping as well as in thicknesses to the lower part of the thicker section farther east. It may be noted from a study of the sections of the Mesaverde near the Grand Hogback and in the Danforth Hills that the principal group of workable coal beds is in the lower part of that formation, immediately overlying a relatively barren zone of 1,000 feet or more. This coal-bearing group is in turn overlain by a considerable thickness of strata containing scattered coal beds or carbonaceous streaks, some of which are of workable thickness. Additional evidence of the removal by erosion of the upper beds in the western part of the field is found in the fact that as these rocks are traced northwestward into Utah they apparently show progressively deeper erosion, without any notable change in the character or grouping of the basal members. The Mesaverde formation may be followed continuously to and beyond Green River, where its outcrop crosses that stream just below the mouth of Ashley Creek in Utah. At this place all of the workable coal group is wanting except one or two coal beds, and these occur at the top of the section, which is roughly estimated as not more than 1,500 feet in thickness.

Not only has a great amount of the Mesaverde formation been eroded from the western part of the White River region, but other and higher Cretaceous formations have probably also been removed from that entire basin, as they are present in adjacent fields to the north and east. In the Yampa coal field the Lewis shale and the Laramie formation overlie the Mesaverde, separating that formation from the succeeding Tertiary sediments, which are similar to those that rest directly upon the Mesaverde in the Rangely field. It is therefore presumed either that beds corresponding to those now found in the Yampa field had been eroded from the Rangely district and vicinity before the deposition of the Tertiary beds began, or that the uppermost Cretaceous beds were never deposited in the Rangely district. In the latter case, the time during which these later beds were being laid down in other regions was marked by dry-land conditions in this district.

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[a] Coal fields of the Danforth Hills and Grand Hogback in northwestern Colorado; Bull. U. S. Geol. Survey No. 316, 1907, p. 266.

The stratigraphic horizon marking the disappearance of beds which are thought to have once been deposited and later eroded before succeeding deposits were laid down represents an interval in the geologic history of the earth probably as important as the time represented by many of the formations that still remain and may be studied at the present day. The causes that brought about first the deposition of certain beds and later the removal of the same material by erosion indicate changes in the earth's crust similar or related to the earth movements that produced the mountain ranges. Although the record of those events, to be interpreted from a study of the strata, may have been wholly or in part obliterated at certain localities, many of the missing clues may be obtained from other places. The horizon of a former land surface that was uplifted and subjected to erosion and subsequently submerged and subjected to renewed sedimentation is known as an erosional unconformity.

The tilted rocks exposed in the ridge north of and approximately parallel to White River between the mouths of Wolf and Red Wash creeks offer what is perhaps the best opportunity for measurements of the Mesaverde formation near the field. An estimate based on a measured line just east of Red Wash Creek (between secs. 13 and 18, 24 and 19, along the township line separating T. 3 N., R. 101 W., and T. 3 N., R. 100 W.) gives a total of only 2,500 feet. The upper limit of the section is defined by an exposure of the varicolored marl characteristic of the overlying Tertiary just east of this line, along the axis of the Red Wash syncline. Some fossils found immediately along the line of this cross section (100 paces southeast of the northeast corner of sec. 36, T. 3 N., R. 101 W., in a conglomerate ledge) also serve to indicate that the top of the formation had been reached and that as complete a section of the Mesaverde as now remains in this part of the field occurs at this place. These fossils consist of internal casts of a species of *Unio* and some indeterminable fragments of leaves. Doctor Stanton considers the *Unio* to be of an age later than the Mesaverde, possibly belonging to Fort Union or related time. He is also of the opinion that it is older than species previously known to have come from the Wasatch formation. No intermediate formation has been recognized in the Rangely field and these rocks are therefore included with the Wasatch formation.

The canyon of White River below Raven Park would seem at first sight to present a most excellent opportunity for obtaining a measurement of the thickness of the Mesaverde formation. Two factors, however, interfere with such a measurement at this locality. The first, which will be described in a subsequent paragraph, is the probable existence of a fault near the mouth of the canyon, and the second is a sharp divergence of dips and strikes along the river banks, caused by irregularity in geologic structure.

As has been explained, the precise determination of the upper limit of the Mesaverde is an especially perplexing problem in and about Raven Park. Near Meeker and along the Grand Hogback between White River and Grand River a bed of coarse bowlder and pebble conglomerate or "pudding stone" with a coarse white-sand matrix marks the boundary between characteristic Mesaverde beds below and the variegated marl and sandstone of the overlying Tertiary. In the Rangely district, however, no such clearly defined stratum was discovered, although some beds of conglomerate not closely resembling the Grand Hogback bed were found. These beds appear to be at or near the top of the Mesaverde formation, but in many places they could not be discovered and the sandstones of the Mesaverde could not be distinguished from those of the overlying beds. Consequently the exact upper limit of the formation could not in all places be determined. In some parts of the Rangely district the variegated colors of the overlying Tertiary beds are less conspicuous, although they are generally recognizable and serve as almost the only distinguishing mark of the transition to Tertiary strata. The occurrence at this horizon of some species of unios and one or more gasteropods, including one which is probably a *Goniobasis*, was not considered determinative, but is thought to indicate the Tertiary age of the beds including them and is considered as a useful clue in the mapping of the Cretaceous-Tertiary boundary at the top of the Mesaverde.

Fossils have been found in all parts of the Mesaverde formation. These indicate that the basal beds are mostly of marine origin, up to and probably including the "white rock." This basal portion of the formation is distinguished as a separate member on the geologic map (Pl. II). Above the "white rock" fresh- and brackish-water invertebrates and plants indicate a change in the body of water in which these beds were formed. The fresh- or brackish-water conditions were not permanent, however, and gave way to true marine conditions when the beds near the top of the formation were deposited. Fresh-water fossils are also found in the lower predominatingly marine beds. The following is a list of the fossils collected from the Mesaverde formation in this field or along the drainage basins of White and Yampa rivers:

Fossils obtained from Mesaverde formation in White River districts.

INVERTEBRATES.[a]

Ostrea subtrigonalis E. and S.
Ostrea glabra var. arcuatilis Meek.
Anomia micronema Meek.
Modiola laticostata (White).
Inoceramus sagensis Owen.
Inoceramus cripsi var. barabini Morton.
Inoceramus erectus Meek.
Unio sp. cf. U. brachyopisthus White.
Unio cf. danæ M. and H.
Corbicula cytheriformis M. and H.
Corbicula occidentalis M. and H.
Cardium speciosum M. and H.
Legumen sp.
Donax? sp.
Mactra formosa M. and H.
Corbula undifera Meek.
Viviparus sp.
Tulotoma thompsoni White.
Campeloma? sp.
Goniobasis? sp.
Baculites compressus Say.

PLANTS.[b]

Halymenites.
Cunninghamites elegans? (Corda) Endl.
Ficus speciossissima Ward.
Ficus squarrosa? Knowlton.
Ficus sp.?
Ficus planicostata Lesq.
Sapindus sp.
Sequoia Reichenbachi (Gein.) Heer.
Dammara cf. D. acicularis Knowlton.
Corylus cf. C. Macquarrii (Forbes) Heer.
Magnolia tenuinervis Lesq.
Zizyphus sp.?
Celastrus sp.
Platanus sp.
Geinitzia sp.

TERTIARY FORMATIONS.

Between the top of the Mesaverde formation and the base of the overlying Tertiary strata an unconformity exists in the Rangely district, as has already been stated. Much difficulty has been experienced in determining precisely the horizon at which this unconformity occurs, as no change in the bedding of the strata has been noted. Definition of the top of the Mesaverde as well as the base of the Tertiary depends on this feature. Both formations contain alternating beds of massive sandstone and sandy shale which are so similar that in many places they can not be distinguished one from another. The chief characteristics of the lower Tertiary beds are the clays or marls of brilliant and variegated colors, which constitute in some places a mass 2,000 feet to possibly 4,000 feet in thickness. The variegated strata are supposed to be of Wasatch age and were so mapped in the Hayden reports. Fossils obtained from the basal part of this formation have been identified as characteristic of the Fort Union formation. The Wasatch is quite distinct as a lithologic unit along the western flank of the Grand Hogback and the Danforth Hills, where it attains a thickness of at least 4,000 feet. In the vicinity of Raven Park, however, these colored clays are much less conspicuous. Below the Cathedral Bluffs red patches are exposed only here and there, and the massive white sandstones very closely resemble those of the Mesaverde formation below.

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[a] Determined by T. W. Stanton.

[b] Determined by F. H. Knowlton.

Overlying the Wasatch or lowest Tertiary formation is a second mass of shale and sandstone without the variegated colors. These rocks have been named Green River group in the earlier geologic work. They are characteristically exposed in escarpments of considerable elevation, among the best examples being those of the Book Cliffs and Cathedral Bluffs, south of Raven Park. These steep scarps stand at elevations of 1,500 to 2,000 feet above the neighboring valleys, and are almost everywhere characterized by the chalky-white appearance of the weathered cliffs as seen at a distance. The Green River formation usually lies nearly horizontal or with a very light dip, and in most places it forms a high mesa or plateau surface, occupying the undisturbed interiors of the great structural basins.

In detail the Green River formation is composed of sandstones and thin-bedded slaty shales, with layers of limestone and calcareous shale. Many beds of oolitic or pisolitic limestone occur, and at some localities they form the major part of the harder beds which the formation contains. In many places the thin-bedded shale is of dark or brownish color when freshly exposed, in marked contrast to the almost universal whitish aspect of nearly all these beds on their weathered edges. The characteristic occurrence of most of these Tertiary beds in areas of slight structural disturbance and their consequent horizontal position are discussed in the section on structure (p. 34).

MODIFICATION OF FORMER CRETACEOUS CLASSIFICATIONS IN THE PRESENT PAPER.

All the names of Cretaceous formations used in the reports of the Hayden, King, and Powell surveys, with the single exception of Dakota sandstone, have been superseded by other names in the foregoing descriptions. The relations of this recently adopted nomenclature to the old classifications and also the relations of those formations to each other are indicated in the accompanying table of correlations. The classification of the Cretaceous strata above the Dakota as Laramie, Lewis, Mesaverde, and Mancos here replaces altogether the older grouping of Laramie, Fox Hills, and Colorado as used by the King and Hayden surveys for this general region. Although the term Laramie is retained in the present classification as the name of the uppermost of the formations of Cretaceous age as they are now recognized, this term is no longer accepted as it was formerly applied by any of the early investigators in this

Table of correlations to explain the relations of the various groupings adopted for western Colorado strata.

[The horizontal arrangement is intended to indicate actual equivalency of the strata. The heavy lines indicate the various conclusions as to the age of the strata thus designated.]

	Hayden, about 1870.	King, Fortieth Parallel Survey, 1875.	Powell, Geology of Uinta Mountains, 1876.	White, Hayden Survey, 1878; Ninth Ann. Rept. U. S. Geol. Survey, 1889.	Cross, San Juan folios, U. S. Geol. Survey, 1899.	Fenneman and Gale, Yampa coal field report, Bull. U. S. Geol. Survey No. 297, 1907.	Present report.	
	Green River.	Uinta. Green River.	Green River.	Green River.			Green River.	Tertiary.
	Wasatch.	Vermilion Creek. (a)		Wasatch.			Wasatch.	
Tertiary.	All coal-bearing formations mapped as Lignitic.		Various formations mapped as Bitter Creek.	Neither unconformity nor hiatus recognized.			Fort Union? (a)	
					Laramie.	Laramie.	Laramie.	Cretaceous.
			(b)		Lewis.	Lewis.	Lewis.	
		Laramie.	Point of Rocks.	Laramie.[c]	Mesaverde.	Mesaverde.	Mesaverde.	
Cretaceous.	Fox Hills. Pierre. Niobrara. Benton.	Fox Hills.	Salt Wells.	Fox Hills.				
		Colorado.	Sulphur Creek.	Colorado.	Mancos.	Mancos.	Mancos.	
	Dakota.	Dakota.	Henrys Fork.	Dakota.	Dakota.	Dakota.	Dakota.	
Jura-Trias.	Jurassic.		Flaming Gorge.	Jurassic.	Gunnison. McElmo.		"Flaming Gorge."	Jurassic.
	Triassic.		White Cliff.	Triassic.	La Plata.		"White Cliff."	

[a] Unconformity.

[b] Local unconformity.

[c] White regarded this Laramie as transitional between the Cretaceous and Tertiary.

particular field—a point that is discussed in detail farther on (see pp. 27–32). This more recently adopted nomenclature has already been introduced into the literature of northwestern Colorado geology.[a] Still more recent stratigraphic studies have confirmed the tentative conclusions of the Yampa coal report, relating to the necessity for a revised nomenclature, and also the expediency of the names there adopted for the northwestern Colorado region.

Although the classifications and conclusions of the early geologic writers on this field have gained wide recognition and become very firmly established in a popular as well as more technical way, there is ample justification and indeed urgent necessity for abandoning entirely this older terminology and revising the basis of its stratigraphic grouping. This revision, as adopted here, is intended to accomplish three specific aims. These are, first, to do away with the uncertainty that prevails with regard to the precise definitions and limits assigned to certain terms by the various authors in the older work, the differing significance attached to the geologic term Colorado being the principal instance; second, to establish a stratigraphic and lithologic basis of separation of the formations instead of the previously adopted paleontologic basis, which depended on distinctions that are always difficult and locally impossible to recognize; third, to call attention to and correct an old and now widespread misinterpretation of the age of the beds formerly called "Laramie" in this field—a group of strata that should never have been included in the formations to which that name was applied, even according to the original somewhat uncertain definition of the term. These points are considered in more detail as follows:

First. The use of the same geologic formation name with varying significance is found in the application made of the term Colorado by the King and Hayden surveys. This disagreement is indicated in the correlation table (p. 27). In the reports of the Fortieth Parallel Survey the term Colorado is defined so as to include a considerably wider stratigraphic range than as it was later used by White in his work with the Hayden Survey. The reasons for this confusion are largely paleontologic, as stated by White in his report.[b] He says:

> While adopting the name "Colorado group" of Mr. King, I, for paleontological reasons chiefly, so restrict its application as to include only what I understand to be equivalent with Nos. 2 and 3 of Meek and Hayden's original section, leaving the equivalent of No. 4 to be included with the strata of the Fox Hills group, instead of with the Colorado group, as Mr. King has done.

The restriction of the Colorado was not successfully applied in the mapping of the Rangely district, where this subdivision could not be traced on a lithologic basis. White's usage of the term has, however, been generally and consistently followed in other fields for thirty years and it is still of great value as a correlation term. As Stanton states, the group is a natural division from a lithologic as well as a paleontologic standpoint east of the Rocky Mountains, where the calcareous Niobrara separates the two dark shales, Benton below and Pierre above.

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[a] The Yampa coal field, Routt County, Colo.: Bull. U. S. Geol. Survey No. 297, 1907.

[b] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, pp. 20–21, 30.

Second. The necessity for the use of stratigraphic and lithologic distinctions as the primary basis in geologic mapping is well brought out by the difficulties that have been encountered in Raven Park and adjoining districts. White himself admits[a] that "all the groups of strata that are referred to the Cretaceous period in this report are, within this district, not only strictly conformable with each other as regards their stratification, but I have never been able to fix upon a plane of demarkation between any of them with entire precision." White's grouping of the strata was made on a purely paleontologic basis, a policy which he considered imperatively necessary[b] for the purpose of establishing at once wide-range correlations over extensive areas. Thus the division planes which he adopted depended entirely on scattering and to a large extent inadequate fossil evidence and not on recognizable changes in the rock strata themselves. His planes of demarkation were thus impossible of precise definition and could never or very rarely be identified exactly in the field. The geologic boundaries he has shown on his maps are therefore scarcely more than mere estimates or are purely arbitrary lines which had to be assumed in the absence of the criteria necessary to establish any actual subdivision. Even if sufficient fossil evidence were everywhere at hand to make such a division it is extremely doubtful if it would serve the most useful purposes, as no one without paleontologic training could appreciate its value when drawn.

Although it now appears to be more practical to map geologic formations in any particular field largely on the basis of lithologic distinctions—that is, changes in the character of the rock strata themselves—no one will question the necessity of paleontologic evidence in determining the position of these rocks in the geologic time scale and their correlation across the larger areas or in discontinuous fields. The errors introduced by some of the older surveys as a result of attempted correlation on the basis of lithologic similarity of rock formations occurring in discontinuous areas have been as many and as serious as those resulting from the use of paleontologic criteria. The argument of the present work is that the more practical method of subdivision should be applied to any specific stratigraphic section. For any one field or basin marked changes in the constitution of the rock strata themselves furnish as important evidence of changes in geography and in conditions of sedimentation during past geologic time as do the fragmentary records of animal life that now happen to be preserved.

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[a] Op. cit., p. 29.

[b] Op. cit., p. 30, line 30.

A part of the confusion in the early geologic mapping based on paleontologic distinctions was probably due to the failure at that time to understand the significance of the so-called Fox Hills fauna. It is likely that the use of the term Fox Hills to define any particular formation representing a specific time interval in the Cretaceous history of the Rocky Mountain region will now be abandoned. This conclusion has been reached by Stanton and others after an extensive study of western Cretaceous stratigraphy, and so far as known to the author is not now disputed by anyone familiar with these problems. As stated by Stanton,[a] "Faunas similar to that of the Fox Hills sandstone have a great vertical range and are likely to be found at any horizon within the Montana group where a littoral or shallow-water facies is developed. The use of the term Fox Hills as a formation or horizon name outside of the original area in South Dakota is therefore of doubtful propriety, as experience has shown."

In most of the fields west of the Rocky Mountains or the Great Plains the term Pierre has also led to some confusion. Sections in central and northern Montana that have been described have defined as the Pierre formation (later named Bearpaw, although still assigned to Pierre age) a shale body overlying the Judith River, Claggett, and Eagle formations. The latter three formations are now considered to be in greater part the equivalents of the Mesaverde formation of northwestern Colorado and southern Wyoming sections. In the Colorado and Wyoming fields, however, Pierre has been used to denote beds which normally underlie the Mesaverde formation. The shales above and below the Mesaverde are of similar lithologic composition, resembling the Pierre shale of the Great Plains region, and also contain fossils that are commonly found in the Pierre of the Great Plains. Pierre is certainly a valid and useful term in the large area where the Niobrara is typically developed and Mesaverde and similar formations do not exist, but probably has no place in a section which also includes either the Mesaverde or the Judith River.

Third: With regard to the previous misinterpretation of the term Laramie so far as it relates to the Raven Park district the solution is clear. None of the rocks in this field to which the name Laramie has hitherto been applied are properly so classed. The Laramie formation in the sense in which the name was originally adopted is almost certainly not represented at all by any of the strata exposed in the immediate vicinity of Raven Park. Either this formation was never deposited in this field or if it was deposited it was completely eroded at a later time, before the overlying Tertiary beds were laid down.

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[a] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: Bull. U. S. Geol. Survey No. 257, 1905, p. 66.

The name Laramie was adopted by agreement between King and Hayden to apply to the Cretaceous strata then thought to lie at the top of that system, conformably above the marine deposits. It was assumed at that time that marine conditions existed throughout a large part of the interior province during most of Cretaceous time, and that these conditions terminated with a succession of crustal movements that uplifted the Rocky and Uinta mountain ranges. Portions of this sea were supposed to have been cut off in interior basins at the time of that upheaval, so that their waters gradually became less and less salty, until the fresh-water conditions which marked Tertiary time were fully established. It was clearly the intention of the early investigators to denote the beds laid down during this transitional stage by a formation name, for which purpose Laramie was agreed upon. In terms of later geologic nomenclature, therefore, Laramie was probably meant to include all the brackish-water deposits which succeeded the Montana, or latest marine sediments then recognized in the Cretaceous system. This formation was less certainly defined by an upper limit, but was in all probability intended to include all strata up to whatever beds should be considered as belonging to the fresh-water or Tertiary basins established after the mountain-building movements already mentioned were completed.

Early investigators did not at first recognize that temporary transitions to brackish and fresh water deposition occurred at various periods during marine Cretaceous time. Such conditions apparently prevailed for a while in certain interior basins at the same time that the normal marine deposits were being laid down in adjoining regions. These periods which preceded the close of the Cretaceous were, however, of short duration and were apparently terminated by incursions of the sea and reestablishment of salt-water conditions. The Judith River beds of Montana and the Mesaverde formation of Colorado are examples of deposits laid down during such periods. Both contain a fauna and flora resembling those of the Laramie and were formerly supposed to be Laramie. Both are now known, however, to represent stages of fresh-water deposition somewhat similar to those which prevailed during Laramie time, but occurring long before the close of the Cretaceous. It is perfectly clear that such beds can not be included under any interpretation which can be reasonably given to the original definition and agreement as to the use of the term Laramie.

The fact that Mesaverde time was succeeded by a considerable period of true marine deposition was entirely unrecognized at the time of the earlier surveys. Evidence of this return of salt-water conditions is found in the existence of a normal succession of marine strata overlying the Mesaverde formation in the Yampa River valley, north of the fields structurally included with those of the White River districts. The Yampa basin contains a great body of dark clay shale with lenticular interbedded sandstones and calcareous layers, overlain by a second large body of sandstones, sandy shales, and coal beds. Of these deposits the lower or shale group (Lewis shale) is of marine origin and the overlying beds indicate a second transitory stage, reintroducing brackish and fresh-water conditions. The later beds are thought to represent, at least in part, the Laramie, so far as the best interpretation of that term is at present understood.

STRUCTURE.

GENERAL FEATURES.

The geologic structure of the region here discussed can best be described by means of graphic sections. Several of these have been constructed to represent the features exhibited in the Rangely district and are reproduced in Pl. III. The locations of the lines along which these cross sections are drawn are shown on the geologic map (Pl. II, pocket) by letters corresponding with those on the sections.

The whole field constitutes only a portion of the huge structur basin that lies south of the Uinta Mountains. The term basin i variously used, but in its structural geologic sense it refers to th attitude of the rock strata and is intended to signify a syncline relatively depressed portion of the earth's crust, commonly retainin beds of the younger geologic formations, while the correspondin beds are very likely to have been worn away over the uplifted po tions that surround and form the rim of the basin. A basin in th sense should not be confused with a topographic basin, which is a commonly understood as a relative depression, but referring to t earth's surface only without any implication as to the attitude of t underlying strata—for instance, a valley or drainage basin. Rav Park is an excellent example of a topographic basin, but is struct ally quite the reverse of a basin, being formed of strata relativ uplifted at the center or axis, and not depressed.

The Raven Park district lies on the northern margin of the Ui Basin, where the younger beds that occupy the major basin are u turned and eroded along the uplifted axes of the Uinta Mount system. The Uinta Basin as a whole lies south of the Uinta Ra in Utah and Colorado. It is limited on the east by the various a of uplift which form the western foothills of the Rocky Mount system. It extends westward to the Wasatch Mountains in Utah a southward to the uplifted areas of the Uncompahgre Plateau a the San Rafael Swell. In the major structural basin, as well as in the subordinate synclines included within it, the axes or deepest

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the subordinate synclines included within it, the axes of deepest

portions of the folds lie in the main parallel to the major axes of the uplifts that border them. Thus within the influence of the Rocky Mountain system all the folds exhibit marked parallelism in a northwest-southeast direction. The axes of the Uinta system trend more nearly east and west, and an extension of the Uinta uplift eastward as a comparatively simple anticline through Axial Basin bends southeastward and merges into the corresponding uplifts and folds of the White River Plateau, which are clearly a part of the Rocky Mountain system. This connecting anticline is comparatively inconspicuous as regards its magnitude of uplift, but it connects the two great mountain systems and separates two huge basins of the younger Cretaceous and Tertiary rocks which lie north and south of it. The basin to the north is described in part as the Washakie Basin in Wyoming, a portion of the greater structural feature known as the Green River Basin, and terminates southeastward in the valley of upper Yampa River in Colorado.

The Colorado portion of the Uinta Basin has been termed the Grand River Basin, and is in a minor way naturally distinct from the larger extension of the Uinta Basin into Utah, being separated by a series of anticlinal or domal uplifts of which the Raven Park fold is one. This series of uplifts has an approximately north-south axis. It is, however, composed of three or more distinct structural domes, to be presently described in detail, whose axes of greater elongation are approximately parallel to each other but oblique to their north-south alignment as a group. The longer axis of the Raven Park anticline lies apparently in extension of the major axis of the whole Grand River Basin. The similar and more pronounced fold of the southern Blue Mountain region lies north of the Raven Park anticline. A less pronounced fold south of the Raven Park anticline will be described as the Douglas Creek uplift. South of the Douglas Creek uplift and beyond the area here considered in detail the Uinta Basin as a whole terminates against the flexures bordering the Uncompahgre Plateau south of Grand River, just as it does against the Uinta axes on the north.

RAVEN PARK ANTICLINE.

The structure of Raven Park is essentially that of a simple anticline or dome of the underlying strata, the valley itself having been eroded from the crest of the uplifted portion. The strata are inclined outward, dipping in all directions from the center or axis of the uplift. The dome is roughly oval in form, the axis or longer diameter lying in an almost due northwest-southeast direction. At either end of the axis the fold flattens and is lost to view, merging into the flexures of adjoining areas. Toward the northwest the two flanks of the flexure unite, the strata becoming approximately horizontal, with a number of minor irregularities, and the fold disappears entirely at a point near the Colorado-Utah State line. Beyond that point all trace of subordinate folds is lost, the strata showing a uniform southward dip away from the higher uplifts to the north and extending in this way westward to the Green River Valley. Southeast of Raven Park the fold apparently terminates in the flat-lying Tertiary beds of the high escarpment known as the Cathedral Bluffs. These strata fill most of the interior of the Grand River Basin. The portions that now remain are, as a rule, horizontal or only very gently flexed or tilted, and constitute most of the high plateau surfaces that characterize that general region.

The Raven Park anticline is not a symmetrical fold. Toward the northeast the strata dip away at light angles, averaging from 4° to 6°, but the dips to the south and southwest are much steeper—from 15° to about 35°—the flexure itself being very abrupt, as is characteristic of most of the folds in the western Cretaceous foothill strata. These steeper dips are found along Raven Ridge and the south side of White River.

As stated, the Raven Park anticline lies midway between similar flexures on the north and the south. All these folds exhibit striking features of similarity and apparent relationship. The most prominent of these features are the character and position of the flexures themselves, and the correspondence in direction of their longer axes. It is of interest to note the gradation of the intensity of uplift that produced the various folds. In the Midland fold to the north the upheaval was sufficient to bring to surface level rocks as old as Carboniferous, but even this uplift is of much less magnitude than similar and greater folds immediately north of it. The Raven Park fold exposes the Mancos shale at its center. The Douglas Creek flexure is broader and of less intensity than that of Raven Park, so that its upper portion is now largely capped by the Mesaverde strata still younger than those found in Raven Park.

MIDLAND UPLIFT.

The Midland uplift was named and described by White[a] in a report of the Hayden Survey. The name is intended to include the anticlinal flexure that forms the southern margin of Blue Mountain (Yampa Plateau of the earlier work), a portion of which was then designated as the Midland Ridge. The southern part of this region of uplift is included in the area of the geologic map and sections that accompany this report (Pls. II and III). It is in many respects the

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[a] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, p. 45.

Formation
ndstone

most striking feature of the region and is of especial interest in connection with a study of the Raven Park uplift because of its similarity in form and parallelism of structure and the greater magnitude of the stratigraphic displacement which it represents. By reason of the greater intensity of its uplift, and also of later erosion along its axis, it brings to view a considerable section of the older strata which underlie Raven Park but are not there exposed.

Like the Raven Park anticline, the Midland uplift exposes at its center beds of weaker texture than those which compose the flanking ridges, and thus a portion of the axis or crest of the uplift is eroded to a valley of comparatively low relief. This valley is in form a great amphitheater about 15 miles in length, inclosed by an almost continuous wall of brilliantly colored strata. This escarpment is a striking feature of the landscape and can be seen from a great expanse of territory to the south as far as and beyond White River valley. It is in form a precipitous wall 1,000 to 1,500 feet in height, composed of brilliantly colored clay or shale capped by ledges of massive white sandstone. The underlying shale and sandstone present a banded appearance, a feature traceable with remarkable uniformity through the entire length of the central or axial basin. The upper beds in the escarpment are of vivid red; the lower part is mainly of a dull greenish-gray color divided by a narrower band of red similar to the brighter-colored strata above. At places the overlying red seems to encroach irregularly upon the gray beds below, but on close inspection it may be seen that this appearance is due to wash and slide and to the stain derived from the overlying material.

The view given in Pl. IV, *B*, is taken from the summit of the cross-bedded white sandstone ridge at the south side of Blue Mountain, and shows the structure and topography of that part of the field. The structure, as explained above, is that of the southern margin of the Midland uplift, with southward-dipping strata of the Jurassic white sandstone in the foreground and the Dakota and Benton ridges to the right and in the distance. The valleys represent the weaker beds that have been eroded. The escarpment in the background to the left is that of the " red beds " in the Midland Ridge.

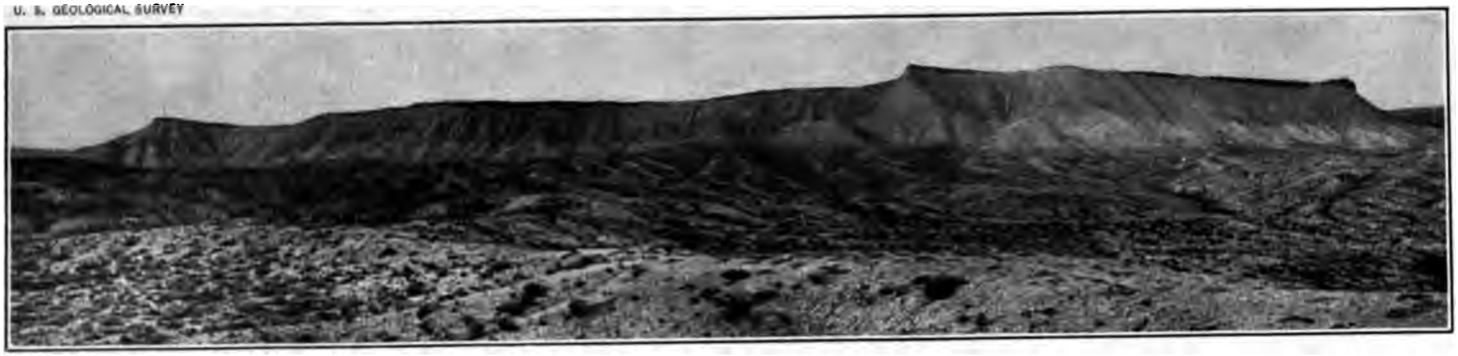
Like the Raven Park uplift this fold is not symmetrical but dips more abruptly on the south than it does in other directions. It is also limited on the north by a still higher upthrust of similar and related structure. The Midland fold pitches down and terminates abruptly toward the west within a mile or two of the Colorado-Utah State line. Throughout the greater part of its extent its principal axis of flexure lies in an approximately due east-west course, parallel to the larger uplifts of the Uinta system on the north. The Midland fold extends toward the east, its axis bending southward in the upper valley of Wolf Creek, and crosses White River at the mouth of that creek. In this portion of its course the axis conforms to the trend of the Raven Park anticline, as it does also with the prevailing structures of all the flexures southwest of this region. Southeast of White River the Midland fold flattens and is lost to view in the lightly dipping strata of the high plateaus of Tertiary strata composing the interior of the Grand River Basin to the south.

RED WASH SYNCLINE.

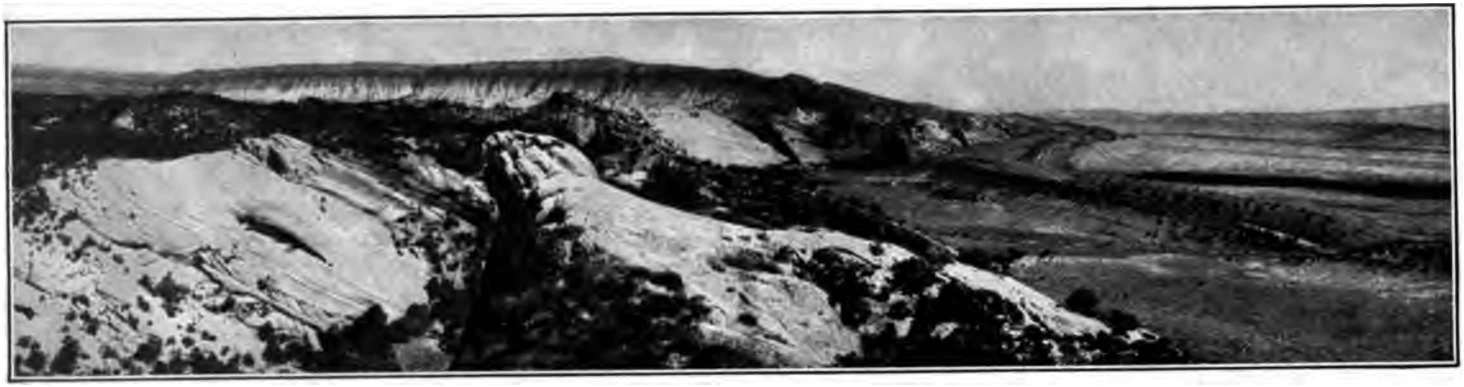
The Raven Park anticline is separated from the Midland uplift by a syncline or depression of the rock strata. This axis of depression enters the Raven Park district from the east, passing approximately along the channel of White River in the vicinity of Angora post-office. From this point it follows a course somewhat north of west, crossing the valley of Red Wash along the eastern margin of the territory represented on the map. It there produces a broad area of low, rolling country, where lightly dipping sandstone ledges of the Mesaverde formation form the principal outcrops along ridges and gulch sides. The varicolored marls of the overlying Tertiary beds remain along this axis in White River valley and extend westward as far as the twelfth auxiliary guide meridian. The axis of the syncline rises to the west and this fold consequently narrows in that direction. This axis may be readily traced westward as far as Willow Creek as a clearly defined flexure of the strata. Beyond that place, with a slight confusion of dips and strikes, as has been explained (pp. 33–34), the strata assume a lighter dip and the syncline is much less marked. It may be traced, however, as a gentle flexure almost as far west as the State line, where it is lost in the same coalescence of subordinate structures into which the Raven Park anticline disappears.

DOUGLAS CREEK UPLIFT.

The Raven Park anticline is terminated on the south by a narrow and rather abrupt syncline separating the uplift from another low anticlinal structure in the valley of Douglas Creek, farther south. This is a broad, low arch of far greater areal extent than the Raven Park fold, but of less intensity of uplift, so that the strata exposed at the crest on the eroded surface and in the valley bottoms are mainly those of the Mesaverde formation. It occupies chiefly the drainage basin of Douglas Creek, a broken, somewhat roughly mountainous district surrounded by the higher escarpment ridges and plateaus of the Tertiary strata. This broad basin of anticlinal structure extends westward approximately to the State line in the vicinity of Dragon, Utah, and is terminated on the south by the high summits of the divide on the Roan or Book Cliffs Plateau. It is limited on the east by the high, precipitous wall of the Cathedral Bluffs. The areal



A. THE "RIM ROCK" IN RAVEN PARK.



B. SOUTHERN MARGIN OF BLUE MOUNTAIN.

extent of this fold is estimated as at least 250 square miles. A large part of this district is coal bearing, and it may eventually prove to be an important coal field.

This uplift lies intermediate between the Raven Park anticline on the north and the uplifted area south of Grand River which forms the northern margin of the Uncompahgre Plateau. It thus completes a north-south series of dome structures which constitute a natural separation of the Grand River Basin of Colorado from the Utah portion of the Uinta Basin, a feature that has already been referred to.

The dips on the flanks of this broad, low fold are very gentle, but there are many irregularities, and the main fold is not, therefore, so well defined nor so readily discerned as the simpler uplifts to the north. The prevailing dips over the larger part of the district are approximately equivalent to the grades of the streams. The oldest strata are exposed on the West Fork of Douglas Creek about 3 miles above the X Bar ranch. Here a small topographic basin is eroded in a shale that clearly belongs near the base of the Mesaverde, but the writer is not certain whether it actually occurs below the lowest sandstone corresponding to the "rim rock" of Raven Park or is just above that bed. By analogy with the Rangely field, the anticlinal structure of this little basin may be considered indicative of a field favorable to prospecting for oil. According to the best information obtained by the writer, however, no indications of oil have been found at the surface and no drilling has been done to determine its presence in strata below the surface.

It is perhaps important to note that the whole region south of the fortieth parallel was erroneously mapped and described in the reports of the Hayden Survey as occupied by the Wasatch formation.[a] For this reason the distribution of the rock formations in this region has not been correctly represented in other publications, nor has its probable economic value as a coal field been appreciated.

UPLIFTS IN ADJOINING REGIONS.

Domes or anticlines similar to the Raven Park uplift occur in many places in the Cretaceous and Tertiary strata west of the Rocky Mountains. Agency Park, the valley in which Meeker is situated, is eroded on a dome that closely resembles the Raven Park fold and exposes the same formation at its crest, although it is of somewhat greater extent. A number of similar, though less conspicuous, folds occur in the Danforth Hills north of Agency Park.

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[a] Endlich, S. F., Report on geology of White River district: Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, pp. 63-131.

An anticline similar to the Raven Park fold, but less pronounced in size and intensity of folding, crosses White River between Raven and Agency parks, at White River post-office. This fold is of some interest as a prospective oil and gas field and is described on page 48.

The Rock Springs uplift in southern Wyoming is a well-known feature, similar in form although of considerably greater extent than either the Raven Park or Agency Park uplift. The Mancos shale is exposed at the center of the Rock Springs uplift, as in the other folds, surrounded by ridges of the coal-bearing Mesaverde formation.

DISTRIBUTION OF STRATA DEPENDENT ON INTENSITY OF DEFORMATION.

The occurrence and distribution of the Tertiary formations in this general region is largely dependent on lack of disturbance in the areas they occupy. They are found in the interior portions of the major structural basins, and in their horizontal or slightly inclined position they constitute the high plateaus which characterize those areas. In normal or horizontal position these beds are little affected by the disintegrating action of surface waters and the elements, except where subjected to the actual corrasion of the streams, and in such places they are chiefly cut away by the attrition of the material mechanically transported over them. The streams cut vertical or steep-walled gashes whose sides retreat but slowly into the neighboring uplands. The recent geologic age of these rocks and their consequent position near the top of the stratigraphic column usually account for their entire disappearance over areas that have been uplifted even to a moderate degree. Their softness and lack of coherence has caused them to be removed from the more abrupt portions of the folds, and their outcrops in folds or tilted positions are usually occupied by low valleys.

Both the Wasatch and Green River formations were involved in the folding that produced the uplifts that have been described. This is shown in certain favorable localities where beds of the younger groups are tilted in the same flexures with the older beds.

FAULTS.

So far as has been observed, faults are not of common occurrence in the Rangely district. A possible fault is marked by an offset in the line of hogbacks developed on the "rim rock" at the upper end of the canyon of White River below Raven Park, near which an oil spring was discovered, as described below. Although this particular locality was not examined with sufficient care to enable the writer to reach a satisfactory conclusion, the very evident offset of the lower hogback ridges is thought to indicate very probably a minor displacement. Several faults in the Douglas Creek valley showed vertical displacements up to 200 feet or more, but these are south of the area included in the accompanying map. Extensive faults are described along the major axes of uplift in the Uinta Mountains, but these are chiefly north of this area and probably have no effect on the accumulation of oil in this field.

DEVELOPMENT OF THE OIL FIELD.

DISCOVERY OF THE OIL.

Attention was first directed to Raven Park as an oil field by the discovery of an oil seep in a spring at the lower end of the park. This spring is said to have been situated on the north bank of the river, near the location of the new land-survey corner between secs. 5, 6, 7, and 8, T. 1 N., R. 102 W. At the present time the position of this spring seems not very well known, and inquiry as to its location was met with the reply that it is probably trampled down by cattle and its flow obscured in the mire. After the report of this discovery a number of companies were organized among the local residents of Meeker and vicinity to prospect and develop the new field. The whole field is now covered by unpatented locations of the so-called "oil placer claims," the various holdings being still divided under the names of the companies by which they were originally taken up. The total area thus controlled is approximately 45,000 acres, or about 70 square miles.

LOCATION OF CLAIMS.

The original claims were staked and surveyed from the accepted corners of the old land surveys. Since their location, however, a resurvey of the whole territory has been authorized by Congress,[a] and the completed plats are now in the General Land Office in Washington and in the surveyor-general's office in Denver. It is the general understanding that lands filed on previous to the completion of the resurvey are subject to patent as filed, even though their outlines do not conform to the lines or corners of the new survey, unless it shall be mutually agreed by all parties concerned to shift the boundaries to correspond to the reestablished survey lines.

DESCRIPTION OF WELLS.

The first well drilled in the field was known as the Pool well, and was put down in the summers of 1901 and 1902. This well is situated in the SE. ¼ NW. ¼ sec. 33, T. 2 N., R. 102 W. (new survey). In this project three of the Meeker companies combined interests in equal shares with the avowed intention, from the beginning of the work, of sinking through the shale to reach the Dakota sandstone.

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[a] Act approved May 28, 1904.

All work in the early developments was planned in accordance with the erroneous estimates of the thickness of the rocks now called Mancos shale, as given in the Hayden reports. The Pool well was drilled to a depth of 2,130 feet, although an oil-bearing sand with a flow said to have been a barrel or so a day was struck at a depth of 750 feet. The hole became crooked, and for this reason it was finally abandoned and lost.

Three wells were sunk by the Requina Company, of Meeker. The first, known as Requina No. 0, was drilled in 1902 in the SE. ¼ SW. ¼ sec. 21, T. 2 N., R. 102 W. (new survey). Oil struck at a depth of 480 feet is reported to have yielded a flow of several barrels a day, as tested by the bailer. The well was continued to a depth of 600 feet, when it also became crooked and was abandoned. The following notes were obtained from memoranda kept by Maj. L. W. Boutwell, who was present at the time the work was done:

> Nov. 13, 1902: Shut down at Requina No. 0 on account of broken injector pump.
>
> Nov. 24, 1902: Pump repaired and started bailing well.
>
> Nov. 25, 1902: Completed bailing of well. Total result was six water tanks filled, holding 5 barrels each, a total of about 30 barrels. This would indicate an average of about 3 barrels per day.

The oil obtained was poured out on the ground and burned.

The Requina No. 1 was drilled a few feet distant from well No. 0, which had just been abandoned, striking the same oil-bearing sand at the same depth. This work was done in 1902 and 1903. Drilling was continued to a depth of 1,680 feet, when a bailer and 1,000 feet of sand line were lost in the hole, and this well was also abandoned. When this well was visited on August 19, 1907, a test of its capacity was in progress, a pump, engine, and small derrick having been temporarily installed for this purpose. The oil obtained was being burned under the steam boiler. A sample of this oil obtained directly from the well and representing the fresh product has been analyzed by Dr. David T. Day, of the United States Geological Survey, and the results are given on page 50.

The Requina No. 2 was sunk in the valley close to the channel of Stinking Creek, about 4 miles north of White River, in the NW. ¼ NW. ¼ sec. 20, T. 2 N., R. 102 W. (new survey). Work was done on this well at intervals from 1903 to 1906. At the time of visit (August, 1907), a derrick and a couple of driller's cabins were still standing. Reports state that water was struck at a depth of 80 feet in coarse, gravelly material, which is said to have been the base of the valley wash, or "adobe" overlying "bed rock." This water is almost certainly the underflow of Stinking Creek; no water has ever been struck in any of the wells within the Mancos shale. It is reported that some gas was found at a depth of about 400 feet, but that no oil was obtained from this well. The drilling was continued to a depth of 2,560 feet, but was finally abandoned because of the accidental parting of the casing and the loss of several hundred feet of it in the hole.

All the Requina wells were drilled with the intention of continuing through the Mancos shale to the Dakota sandstone. Each hole was lost or abandoned through accident.

Two wells were sunk by the Meeker Company, also of Meeker. Both of the wells of this company were drilled to the first oil horizon and discontinued at or near that depth. The well known as Meeker No. 1 is situated in the NW. ¼ NW. ¼ sec. 28, T. 2 N., R. 102 W. (new survey), about one-fourth mile southwest of the Requina wells Nos. 0 and 1. This well is said to have struck oil at a depth of 736 feet, and the hole was drilled to a total depth of 771 feet. At present the site is marked by a metal tank partly filled with oil. This well is said to have shown a flow similar to or slightly less than that of the near-by Requina wells.

The Meeker No. 2 was sunk in 1903, almost exactly 1 mile due east of the Meeker No. 1, in the NW. ¼ NW. ¼ sec. 27, T. 2 N., R. 102 W. (new survey). The well is said to have struck what were thought to be the same oil-bearing sands as those found in the wells already described at a depth of 1,002 feet, when work was discontinued. No oil was obtained from this hole.

The second attempt, by combined interest, to prospect the so-called "deep sands" (meaning thereby the supposed oil pool in the Dakota sandstone) was made in 1903 by drilling the well known as the Union. The site selected was on the northeast side of Raven Park, slightly over half a mile from the "rim rock," in the middle of the west side of sec. 16, T. 2 N., R. 102 W., near the quarter-section corner of the new survey. The adoption of this site was based on an application of the anticlinal theory, as explained on page 34. On the assumption that oil would be found on the flanks of the anticline and that gas would occupy the summit, the site was selected near the margin of the basin, a location giving nearly the maximum thickness of the shale body available from the valley to be passed through before the Dakota sandstone could be reached. This well, known as the first Union, was commenced in 1903 and the hole drilled to a depth of 1,300 feet. Oil was found at a depth of 584 feet, but was cased off and the drilling continued. The hole was finally abandoned owing to the loss of a string of tools due to collapsing casing.

The second Union well was put down on approximately the same site as the first, striking the first oil sand at the same depth as before. This well was also commenced in 1903 and continued at intervals until April 15, 1907, when the rig took fire while still at work and the whole surface equipment was lost. The depth of the hole is

3,655 feet, and the well is said to be still in good condition. It is cased to a depth of 2,974 feet with a string of casing made up of 1,228 feet 8½-inch, 1,332 feet 6⅝-inch, and 414 feet 5-inch.[a] The following is a record of the strata passed through; it is said to be somewhat incomplete on account of the destruction of a part of the data at the time of the burning of the rig:

Record of second Union well, Raven Park.

[Sybert and Joe Trachta, drillers.]

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, dark, at bottom of which small oil-bearing was struck	584	584
Shale, dark	816	1,400
Shale, light colored	200	1,600
Shale, dark, much of it of purple color	839	2,439
Shale, very light colored, drillings being nearly white	41	2,480
Sand, shaly	5	2,485
Shale, dark, with fine lines of white, very rotten	194	2,679
Sand, flinty, alternating with rotten shale	58	2,737
Shale, dark	343	3,080
Shale, black, a little sandy	170	3,250
Shale, hard, black, alternating with light-colored shale	405	3,655

From the manner in which the drill was worn it is supposed to have penetrated hard sandstone at the bottom of the well. This bed is locally supposed to be that of the Benton horizon already described (p. 15), and is reported to have contained fossils, none of which, however, were saved.

In the summer and fall of 1907 several new wells were drilled and some of the older wells were systematically pumped as a test of capacity, under the supervision of Mr. J. H. Hunt, of Haywards, Cal. Of the older wells the only ones available for the test were the Meeker No. 1 and the Requina No. 1. At present writing (December, 1907) it is understood that this work is still progressing and that systematic prospecting of the field will be pushed. It is also reported that five new wells have been drilled, of which four are claimed to have struck oil. Mr. Hunt gives the following statement with regard to his work in the field:

> Altogether my experiments and tests show that oil is found in all the wells except two, at depths from 400 to 700 feet below the surface. The wells cover a distance of about 3 miles from north to south and 1½ miles from east to west. The oil is of a uniform character and in all wells rises to the same level, approximately 360 feet below the surface. By continued pumping the production increases. The formation in which the oil is found is sand and shale mixed, varying in thickness from a few feet to 45 feet. By shooting with nitroglycerine the flow is apparently increased, although we have not yet experimented sufficiently to determine the size shot which is most effective. The production of both the wells shot was increased, but the formation is so hard that neither well was caved in, indicating that they will stand a still heavier shot without damage.

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[a] Information received from Mr. Henry J. Hay, of Meeker.

OCCURRENCE OF THE OIL.

ATTEMPTED APPLICATION OF THE ANTICLINAL THEORY IN THE RANGELY FIELD.

The scientific study of an oil or gas field from the standpoint of the geologist is the only means worth consideration by which the probable presence or absence of these substances in depth may be predicted in advance of actual drilling. In such a study lies the only hope of eliminating any of the large number of failures and the consequent loss of capital so often involved in random drilling in the search for productive sites. However, no geologist or mining engineer can yet recognize with certainty the essential criteria that determine productive pools, nor can he say even in a well-known field what new locations will prove productive. At best such statements can be no more than mere probabilities. In a new field conditions are still more uncertain, and specific knowledge of the occurrence of oil can be obtained in no other way than by actual drilling. An intelligent study of the geologic structure and the formations is the only means of arriving at even a partial understanding of the occurrence of the oil or gas.

The interests that have controlled the prospecting in the Rangely oil field have been for the most part local, distributed among the older residents of the country, who were personally acquainted with the field and with the work that was being done. All of the preliminary drilling seems to have been directed by an intelligent effort to apply the structural or anticlinal theory of the accumulation of oil and gas, which has appeared to explain so successfully some of the oil pools found in the fields of West Virginia and adjacent States.[a]

C. A. White, in the Hayden report, described this valley as eroded from the crest of an anticline or dome and suggested it as a field favorable to the location of artesian wells, should they ever be desired—a prediction which he also stated was based wholly on its geologic structure. With the discovery of oil, the prediction of artesian conditions suggested flowing oil wells. The anticlinal structure of the field suggested, further, the application of the anticlinal theory in this region. Several wells have now been drilled to considerable depth in search of the Dakota "sands." This formation has been thought to fulfill the assumed requirements as a principal storage reservoir for the oil. The theories on which these assumptions are based are briefly reviewed in the following paragraph. In the application of these theories the estimates of the Hayden report for the thickness of the Mancos shale (then termed Colorado and lower part of the Fox Hills) were at first accepted. The figures and sections of that report indicated that the Dakota would be found at no great depth in the valley lands. The wells that have been drilled as yet have failed to reach the base of the shale and it is now clear that the first estimates of its thickness were far too small.

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[a] White, I. C., The Mannington oil field [West Virginia] and the history of its development: Bull. Geol. Soc. America, vol. 3, 1892, pp. 193–216. The geology of petroleum and natural gas: Rept. West Virginia Geol. Survey, vol. 1, 1899, pp. 155–195.

It is undoubtedly true that in many or most oil fields some well-defined relationship exists between the structure—that is, anticlines and synclines in the strata—and the distribution of the oil pools. It is probable also that this relationship is not so simple as exponents of the anticlinal theory from time to time have been led to believe.

After the discovery of the oil spring, attention was attracted to Raven Park as an oil field by the suggestion of its quaquaversal[*] structure, which has been commonly referred to locally as a "perfect anticline." It was at once inferred that in this area were to be found the ideal conditions for the accumulation of a large body of oil, according to the postulates of the anticlinal theory. The conditions assumed by the anticlinal theory as controlling the accumulation of oil and gas are briefly as follows:

(*a*) Porosity of a reservoir rock, which is commonly a stratum of sandstone or sandy rock, capable of containing the oil supply in the interstices between the sand grains. This is generally known as an oil sand and is in many places of sandy composition, although it may be a fractured shale, or even limestone, sufficiently porous to allow the accumulation of oil.

(*b*) An impervious cover or cap rock to serve as a seal and prevent the escape of the oil and gas in an upward direction.

(*c*) Geologic structure or folds in the rock, favoring the accumulation of the oil and gas in certain localities by draining these substances from more extensive areas of adjoining beds less favorably situated for their retention.

(*d*) Saturation of the rocks by ground water, on which the oil will move by reason of its lighter specific gravity, and therefore be forced into the upper parts of the folds—that is, toward the crests of the anticlines.

Oil and gas are commonly found together. According to this theory the gas may be expected above the oil. It is most frequently found in the crests of the anticlines. Small folds or irregularities in the rock structure may hold some of the gas farther down the flanks of the anticlines, or even in parts of the synclines; or, as another condition, less permeable portions of the reservoir stratum may also imprison both the oil and gas below the summit of the fold.

This theory is based on the assumption of the presence of water in the oil sand. Experience has shown, however, that although partial saturation is the condition most generally encountered, yet at a great many places, in both the eastern and the western oil fields, no water is present. These conditions present many modifications of the original theory. Thus the oil may be found almost anywhere with reference to the geologic structure, its position in many localities apparently depending largely on the presence or absence of ground water. The places of accumulation in dry rock are thought to be at or near the bottom of the synclines, or the lowest point of the porous medium, or at any point where the slope of the rock is not sufficient to overcome the friction that retards the movement of the oil. In porous rocks only partly filled with water the oil probably accumulates at and just above the ground-water level, or above the level of saturation. This level may be fairly constant in one basin or structural feature, but probably varies greatly in different basins or in different sands in the same basin. As most of these considerations depend on the position of the ground water and its relation to the oil, they do not seem to apply to a discussion of the oil as it is found in the Rangely field.

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[*] "Dip of strata in all directions away from a center."—White, C. A., Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, footnote, p. 42.

In the first attempted application of the anticlinal theory to the Rangely field, it was pointed out that the Mancos shale (then known as the Colorado and Fox Hills) would furnish the required impervious cap rock. The Dakota sandstone, locally referred to as the Dakota " sands," was assumed to form the requisite porous stratum for the storage of the oil. Attention was called to the fact that White had already predicted that the Dakota would be a source of artesian water, and this water was therefore expected to provide the degree of saturation required to cause the oil to rise into the anticline and to afford a hydrostatic pressure which it was supposed would also produce flowing wells. The spring containing oil at the lower end of the park was thought to be a seepage from this reservoir along a somewhat indefinite fault. (See p. 38.) The first wells drilled in the field were therefore put down with a view to penetrating the overlying shale as far as the Dakota sandstone. The numerous failures from one cause and another to accomplish this aim have been described.

GEOLOGIC RELATIONS IN THE RANGELY FIELD.

The wells that have been drilled in the Rangely field have discovered one or more oil-bearing sands in the body of the Mancos shale. But one oil sand has been found in any one well, and there seems to be a rather indefinite belief or assumption on the part of the local operators that this lies everywhere at one and the same horizon. If the reports of the depths of the oil sand are correct, this assumption does not seem to be warrantable. Any single horizon at the depths recorded in the various wells would not accord with the recognized general structure of the field.

Records kept by the drillers and observations at the outcrops of the Mancos shale show the existence of beds of more or less sandy composition at various horizons within the formation. The well records obtainable are incomplete and not very specific in their description. There seems to be considerable uncertainty, even among those who are most familiar with the work as it was done or who have actually done the drilling, as to the precise nature of the beds in which the oil was found. In a personal communication Mr. Henry J. Hay, of Meeker, states:

> As to the thickness of the oil sand I can not say exactly. Sybert, who drilled the Union to the first sand, thought not over 2 feet, and perhaps less; but Trachta thinks it is greater. No other sand beds were found except in the Union well.

The following note was received from Mr. Joseph Trachta, who has had charge of most of the drilling in the field:

> In regard to the layer where they strike the upper strata of oil I wish to say that it is not a sand layer. It is a hard gritty shale. It is much grittier than the other shale. It looks very much the same all the way through, only a little darker. The gritty shale I speak of is about 100 feet thick and you strike oil through that 100 feet somewhere. The same gritty shale will not decompose to clay as quickly as the other for the reason that it is harder, but is not like the sand we struck at the bottom of the Union well, for that was sand.

The quotations given above are at present the only available descriptions of the nature of the beds that contain the oil as they have been encountered in the wells.

The oil-bearing sands of the Rangely field are probably more in the nature of lenses forming completely inclosed and isolated reservoirs than of " pools " in the sense implied by the anticlinal theory. This conclusion is based mainly on a study of the general characteristics of the strata observed at their outcrops, for the small amount of well drilling that has been done in the field has not supplied sufficient data from which to determine this feature. The lenticular character of almost all the individual beds observed along the outcrops of the Mancos and associated formations is strong presumptive evidence of their similar discontinuity in depth. Like all the minor members of the Cretaceous strata in general, particular beds are found to thicken and thin from place to place along their outcrops or even to disappear entirely, some of them very abruptly, although the features which characterize these particular beds recur at many places at what appears to be the same horizon, over widely extended areas. This irregularity of bedding is more marked in the smaller or thinner strata than in the more prominent members.

Sandy beds, or even strata of fairly massive sandstone, are known to occur along the outcrop of the Mancos shale at some localities outside of Raven Park. An example may be noted in Agency Park, where such sandy beds form a minor hogback in the valley of Mancos shale. Similar beds are present in the upper valley of Coal Creek east of "The Transfer," in eastern Rio Blanco County.[a] So far as known there are no beds in the Raven Park district as prominent as these just cited. From the descriptions of the well drillers, however, it is assumed that some minor beds of this character do occur. In all of this discussion it is recognized that the zones of oil accumulation commonly referred to as sands may not be true sands, but merely porous strata of any constitution in which the oil can gather. The variability and discontinuity of the rocks described are not, however, confined to any one particular feature, such as their sandy composition, as has frequently been observed in the field, but seem to be shown no less by all other physical characteristics and therefore probably apply with equal certainty to the feature of porosity.

The oil-bearing sands that have been struck have been entirely free from water and apparently from the influence of any hydrostatic pressure. The body of the shale itself appears to be wholly barren of water, to which it seems to offer an impervious barrier. If the oil bodies of the Rangely field are in truth contained in isolated or completely inclosed reservoirs they can hardly be expected to exhibit artesian conditions to any marked degree. If, however, a tilted reservoir is tapped somewhere below the upper surface of its contained oil this fluid would of course seek its level in the opened well, or might even be forced higher by a pressure of gas confined in the reservoir above the oil. In any case, it seems clear that whatever artesian conditions may exist in the Dakota sandstone or below that stratum, they are confined beneath the main body of the impervious Mancos shale and do not affect the distribution of the upper oil bodies.

The presence of oil in the Dakota sandstone appears to be a problem of purely speculative nature which can be proved only by the drill. No evidence of oil has ever been found in the outcrop of the Dakota beds in the neighborhood of the Rangely field. The inference of its presence in those beds is therefore based entirely on the supposition that their constitution offers a reservoir particularly well adapted to oil accumulation. This is entirely within the bounds of possibility, as is also the existence of artesian conditions in view of the structure and exposure of the Dakota strata in the apparently favorable catchment area at the south side of Blue

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[a] Illustrated in the cross section published with the geologic map of that district in Bull. U. S. Geol. Survey No. 315, 1907, Pl. III.

Mountain. Oil is reported as occurring in the Dakota sandstone at Turkey Creek and near Golden City, in the Denver Basin.[a]

THE WHITE RIVER FIELD.

In connection with a discussion of the occurrence of oil in the Rangely field, it is interesting to note that some indications of a similar field have been noted on Blacks Gulch, 40 miles east of Rangely in the White River valley. Blacks Gulch opens into White River from the north 20 miles below Meeker. It is near the crest of a minor anticlinal fold, the longer axis of which crosses White River in a north-south direction near the mouth of Piceance Creek at White River post-office. This fold is a low dome of the rocks, exposing the Wasatch strata at the surface, surrounded by escarpments of the Green River formation on all sides. The dips are all light, being about 3° toward the east, increasing to 10° or so south of the river and to about 5° toward the west. Gas is said to have been found by Tom Scarritt, a cowboy, by the accidental igniting of a small flow from a lighted match. A small derrick was set up and a hole drilled to a depth of 400 feet and abandoned. According to reports, a second well was sunk about half a mile farther up the gulch. Here at a depth of 538 feet gas was struck under such pressure that the derrick was destroyed and the driller seriously injured. The gas burned with a blue flame and under much pressure for six months, when it stopped abruptly. The fact that the tools have been left in the hole leads to the supposition that it became suddenly blocked. Gas is also said to be issuing along this same anticline south of the river, at the locality known as Alkali Flats. So far as known no oil has yet been obtained in this field. It resembles the Rangely field only in its geologic structure, the strata being of much later age and overlying by many thousands of feet the oil-bearing beds of the Rangely district.

COMPARISON WITH OTHER KNOWN FIELDS.

Oil has been found at approximately the same geologic horizon as in the Rangely district in a number of fields of this same general region, notably in other parts of Colorado and in Wyoming. Among these may be cited the Florence and Boulder fields,[b] and some flows or seeps in the eastern part of Routt County, Colo. In Wyoming a basin similar to the Raven Park basin in structure and topography has been prospected east of Rock Springs, on the Union Pacific Railroad. It is understood that the work at that locality was undertaken wholly from the suggestion of the anticlinal structure of the field. Although several holes were sunk to a considerable depth in the Mancos shale, it is said that neither oil, gas, nor water was found in that formation. Occurrences of oil in Uinta County, Wyo., some of which are at a horizon analogous to that of the Rangely oil, are described by Veatch and Schultz.[a]

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[a] Lakes, Arthur, Oil in Colorado: Mines and Minerals, vol. 22, 1902, p. 257.

[b] Fenneman, N. M., The Boulder (Colorado) oil field: Bull. U. S. Geol. Survey No. 213, 1903, pp. 322–332; Bull. No. 225, 1904, pp. 383–391; The Florence (Colorado) oil field: Bull. No. 260, 1905, pp. 436–440.

It has been suggested by some of those interested in the Rangely field that conditions here may be held to be more comparable with those of the California fields than with those of the oil fields of the eastern United States. It is believed, however, that this view is not well founded. The California fields are of great complexity of structure, the oil occurring in almost every conceivable structural situation—along faults, in synclines, or in anticlines—and it is thought that no clear understanding has yet been reached of the conditions controlling the accumulation of oil in certain beds there. No direct relationship can be traced to the situation in the Rangely field.

It has also been suggested, and probably with more reason, that the Rangely field may be compared to the Kansas-Oklahoma oil and gas fields.[b] In those districts the oil, though occurring in a much older formation geologically, is said to be found in sandstones interbedded with shale, in lenticular bodies or completely inclosed reservoirs. The geologic structure of those fields is, however, much more simple than that of the Rangely field, being that of a fairly uniform monocline, with a northwesterly to westerly dip of about 20 to 25 feet per mile.

QUALITY OF THE OIL.

PHYSICAL PROPERTIES.

The color of the Rangely oil is clear light red, with strong green fluorescence, closely resembling that of many of the Pennsylvania oils, although perhaps slightly darker than the average. Its odor is like that of kerosene, much resembling that of a refined oil. It is apparently free from sulphur. The specific gravity of the crude oil from Requina well No. 1 is 0.8092, or 44° Baumé. It would therefore be described as a very light, thin oil.

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[a] **Veatch, A. C.**, Coal and oil in Uinta County, Wyo.: Bull. U. S. Geol. Survey No. 285, 1906, pp. 331–353: Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: Prof. Paper U. S. Geol. Survey No. 56, 1907. Schultz, A. R., The Labarge oil field, central Uinta County, Wyo.: Bull. U. S. Geol. Survey No. 340, 1908.

[b] **Adams, G. I.**, and others, Economic geology of the Iola quadrangle, Kansas: Bull. U. S. Geol. Survey No. 238, 1904. Schrader, F. C., and Haworth, E., Economic geology of the Independence quadrangle, Kansas: Bull. U. S. Geol. Survey No. 296, 1906.

CHEMICAL PROPERTIES.

An analysis of the Rangely oil, reported as made by the Standard Oil Company, and already used in the published notes and descriptions of the Rangely field, is as follows:

Analysis of Rangely oil.

[By Standard Oil Company.]

Crude oil, gravity, 43.6° Baumé; burns at 60°.	Per cent.
Light naphtha, gravity, 70.3° Baumé	7
Heavy naphtha, gravity, 61.1° Baumé	12
Illuminating oil, gravity, 45.1° Baumé; flashes at 90°; burns at 116°	60
Paraffin, gravity, 32.8° Baumé	20
Coke and waste	1

The oil is free from sulphur compounds.

A sample of the oil collected fresh from the pump that was running at the Requina No. 1 well on August 19, 1907, was distilled by Dr. David T. Day, of the United States Geological Survey, giving the following results:

Analysis of Rangely oil from Requina No. 1 well.

[By David T. Day.]

Initial boiling point, 48° C.	Per cent.
Gasoline and naphtha (below 150° C.), specific gravity 0.68	25
Illuminating oil (150° C. to 300° C.), specific gravity 0.751	45
Residue (above 300° C.)	27
Loss	3

The oil contains no water. The residue contains much paraffin wax, and there is no asphalt in the sample.

WATER SUPPLY OF THE RAVEN PARK DISTRICT.

GENERAL.

The question of water supply is important to all interests in Raven Park and vicinity, whether engaged in agriculture, stock raising, or the development of natural resources. The annual rainfall is small, and the climate may be described as semiarid. West of the Rocky Mountains the aridity of this plateau province becomes more and more pronounced away from the higher mountain masses, and Raven Park may be said to lie on the border land between the badlands, or more typically desert regions farther west, and the productive basins and valleys of the mountain foothills. A great extent of pasture lands of much value to stockmen is available here only as a winter range when the snow lies on the ground, being wholly destitute of water during the summer season. This is especially true of the territory south of Raven Park and west of Douglas Creek, locally known as the "park country" and designated on some of the maps Rabbit Hills.

AVAILABLE SUPPLIES.

Near the Rangely district only White River and two of its principal tributaries, Douglas Creek and Spring Creek, retain water in their channels throughout the year. In drier seasons both these creeks are said to dry up in the summer, although they have flowed continuously for the last two seasons. The water supply of the Raven Park settlement, both for domestic use and for irrigating the land, is taken from White River, which flows with a good volume and a moderately swift current throughout the year. The stream has a normal width through Raven Park of 2 to 4 chains, or an average of about 200 feet. It pursues a meandering course through the bottom lands, but has a number of slight rapids or riffles over bowlder and gravel bottoms. Its average rate of fall across the park is about 12 feet per mile in a straight course down the valley, and about the same in the canyon above the park. Recent gagings of White River by the United States Geological Survey are quoted in the following tables:[a]

Discharge measurements of White River.

At Meeker, Rio Blanco County, Colo.						At Ignacio, Uinta county, Utah.[b]					
Date.	Width of river.	Area of cross section.	Mean velocity.	Gage height.	Discharge.	Date.	Width of river.	Area of cross section.	Mean velocity.	Gage height.	Discharge.
[a] 1906.	*Feet.*	*Sq.ft.*	*Ft. per sec.*	*Feet.*	*Sec.-feet.*	1906.	*Feet.*	*Sq.ft.*	*Ft. per sec.*	*Feet.*	*Sec.-feet.*
						Apr. 17	72	184	3.19	3.60	587
						Apr. 18	73	198	3.43	3.78	679
Apr. 23	79	267	3.67	4.60	980						
May 4	79	240	3.11	4.39	747						
						May 13	80	506	4.56	6.60	2,308
May 17	78	326	6.42	5.50	2,007						
May 22	78	380	8.57	6.15	3,256						
May 31	78	343	6.94	5.65	2,383						
June 8	78	336	6.69	5.55	2,249						
June 23	78	310	6.41	5.47	1,988						
						June 24	89	631	3.10	6.20	1,955
July 3	78	267	3.76	4.60	1,014						
						July 19	72	285	3.27	4.28	931
July 24	78	187	3.48	4.05	651						
Aug. 10	78	167	2.11	3.85	356						
Aug. 20	78	172	2.15	3.90	369						

[a] Discharge measurements at regular stations; estimated monthly run-off based on daily readings of gage height for stations named.

[b] 18 miles northwest of Dragon, Utah.

Estimated monthly discharge of White River.

At Meeker.		At Ignacio.	
Date.	Total in acre-feet.	Date.	Total in acre-feet.
1906.		1906.	
April	37,400	April	47,800
May	129,000	May	123,000
June	151,000	June	133,000
July	51,400	July	58,400
August	22,800	August	38,600
September	20,500	September	42,100
October	18,000	October	34,400

White River has its principal headwaters in the wooded "Flat-tops" of the White River Plateau, 70 or 80 miles east of the Rangely field. In its upper course, or above Agency Park, this stream is normally a clear, fresh mountain stream. There are some scattering settlements and irrigation along the narrow bottoms in this upper valley, but the volume and swift current of the river at that part of its course seem ample security against appreciable deterioration in the quality of its water. In Agency Park the stream enters on the areas of younger and less consolidated Cretaceous strata, and from this point down the water rapidly loses the freshness and clarity of its upper course. Many ditches divert water for irrigation and return it to the stream more or less charged with alkaline salts from the meadow soils and in practically all cases considerably polluted by cattle and surface refuse. In Agency Park, as also lower on its course during wet seasons, the tributaries empty heavily charged alkaline waters into the main stream, most of that material being leached from the soils of the younger Cretaceous and Tertiary strata.

Below Powell Park the territory drained by the lateral tributaries of the main stream is composed on the north of badland drains of the "Crooked Wash," or Coyote Basin, and the valleys of Wolf Creek and Red Wash, with numerous other smaller drains. From the south side the extensive drainage basins of Piceance and Yellow creeks and other smaller streams from the Roan or Book Cliffs Plateau pour their alkaline waters into the main stream. In times of flood, as in the spring and early summer, and at frequent intervals in the summer months during the brief and violent storms which are characteristic of the region, all of this lower tributary drainage empties a great volume of thick, muddy water into the main channel, making the river water much of the time heavy with mud and clay and surface refuse. At times of such turbidity the river water has a foul odor, suggestive of putrefying flesh, which is, however, thought to come from the clay that is suspended in the moving water. Along its lower course, in the vicinity of Raven Park, White River seldom runs clear for long at a time. The constantly recurring storms at one locality or another in its upper valley keep its water in a condition which is by nature distasteful to man and beast. The question of its effect on the animal system is open to much conjecture, and with increasing population of the district may become a vital issue.

OBJECTIONABLE FEATURES OF THE WHITE RIVER WATER.

The normally distasteful condition of the river water during most seasons of the year is evidently a source of growing complaint among the settlers. Whether rightfully or not, to its effects have been attributed various maladies among those more or less in ill health who are compelled to depend on its use. Its most apparent objections are its turbidity and to a less extent perhaps the odor which seems to accompany this condition when extreme. This turbidity is of course due largely to mechanically suspended sediment that settles out readily when the water is allowed to stand undisturbed. In view of this fact it is a prevalent custom among the residents to dip the water first into a settling barrel at the river bank, whence the supply is carried from time to time to the houses in pails. The suspended matter is so fine and sticky that its removal by filtration would be difficult.

An objection hardly less evident than its muddy condition to those who give the subject any consideration is the constant presence of dead and putrefying animals in the tributary channels and also along the main stream. In a country so largely given to cattle raising it is inevitable that many dead animals must constantly lie scattered about the country. It is perhaps an unfortunate instinct that leads the sick and injured animals to these watering places, where their dead bodies very often pollute the supply for all the rest of the herd, if not also for human use. Flood seasons or heavy storms sweep the refuse from such decay into the main stream. It is said that in winter great numbers of cattle break through the ice and are drowned. Their bodies then lodge in the stream until the breaking up of the ice in spring, when they are passed on down the stream with the high waters. The effect of such decaying matter on the water as a whole, though very unpleasant to consider, is perhaps not yet proved to be essentially harmful, in view of the extreme dilution of the objectionable matter with the total volume of water. The organisms of decay of both organic and vegetable matter, though often offensive to the senses, are not necessarily the vitally dangerous elements of a polluted drinking water. The most dangerous elements to human life are certain specific germs of disease, such as those of cholera and typhoid, which propagate and spread only from sources that contain those germs in advance. So long as these diseases are absent from the drainage basin of White River it seems fair to assume that their germs are not contained in the river water.

A further source of objection may be found in the fact that the river water itself may also exert a harmful influence upon the human system by reason of its chemically dissolved constituents. These are clearly present to a rather marked degree, so that the water is described as "hard." The hardness of a water is due to the presence of alkaline carbonates such as those of calcium, sodium, and magnesium, or to the alkaline sulphates, chlorides, and nitrates. The carbonates produce what is known as temporary hardness, because it may be remedied by boiling. Water containing the constituents of the second group is permanently hard—that is, it remains so even after it has been boiled. The hardness of the White River water is of the permanent kind.

None of these dissolved constituents are of the nature of actively poisonous substances, but the effect of the water on persons unaccustomed to it or to other similarly hard waters is pretty clear evidence of a certain amount of activity. Chemical analyses of the inorganic constituents may be relied on to define very clearly the nature of these dissolved mineral substances, and a fair estimate of its probable effect on the human system from this cause only may be thereby obtained.

With this purpose in view a sample of White River water .was collected by the writer from the main stream just above the Rangely bridge on August 26, 1907. The water at that time was in a somewhat turbid condition, and though the river was not so low nor the water so clear as it had been at times during the month, its condition was not at all an extreme of flood or muddiness, and the sample is considered to represent a very fair average. This water has been analyzed in the laboratory of the United States Geological Survey at Washington, with the following results:

Analysis of White River water collected at the iron bridge, Rangely, Colo., August 26, 1907.

[By R. B. Dole.]

	Parts per million.
Total suspended solids	5,000
Total dissolved solids at 180° C	400

SUSPENDED MATTER.

	Per cent.
Insoluble in HCl (sand, clay, silica, etc.)	71
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	11
Calcium (Ca)	.13
Magnesium (Mg)	.05
Sulphate radicle (SO_4)	Trace.
Organic and volatile matter	16
Undetermined	1.82
	100

DISSOLVED CONSTITUENTS.

	Parts per million.
Silica (SiO_2)	20
Iron (Fe)	1.5
Calcium (Ca)	66
Magnesium (Mg)	24
Sodium and potassium (NaK)	35
Carbonate radicle (NO_3)	5.5
Bicarbonate radicle (HCO_3)	194
Sulphate radicle (SO_4)	146
Chlorine (Cl)	9.3
	501.30

There is apparently no poisonous mineral matter in the water in sufficient quantity to do any harm. The suspended matter is very high and is of such fine, sticky, or "gumbo" character that its removal by filtration without coagulant would be difficult. The sulphates are rather high and calcium-sulphate scale would doubtless result from the use of the water in boilers. If carefully filtered the water would be sufficiently good for domestic use, but in its raw state it is absolutely unacceptable.

USE OF ICE.

It has been an established custom among some of the older residents of Raven Park and vicinity to preserve ice from the river in winter for their summer supply of drinking water. This custom has several important advantages and is to be heartily indorsed. The ice is obtained when the surface of the river is covered and for the most part securely sealed. Refuse and objectionable matter are in the main frozen also, and decay is arrested, so that very little of such matter can gain access to the flowing water, or if it does it lies essentially inert. The water at this time is derived largely from melted snow and ice collected from a frozen ground surface and so is unusually free from the alkaline salts which enter so largely into its composition in the summer. The process of freezing itself excludes a large proportion of the chemically dissolved constituents. It is well known that the ice formed on the salt water of the ocean includes but a small percentage of the normally contained salt.

SPRINGS.

Aside from White River itself there is but little water to be had over a rather extensive area, especially in the lower valley lands bordering the river basin. A few springs are known among the sandstone ridges bordering Raven Park, and a number of them are indicated on the topographic map (Pl. I). Some of these are of good though usually hard water. The following list gives the location of those that are best known or that were found in the present survey:

Springs and water holes in Raven Park district away from White River.

Name.	Location.	Remarks.
Nate Spring	In Nate Spring Gulch, sec. 34, T. 3 N., R. 102 W.	
Iron Spring	SE. ¼ sec. 35, T. 3 N., R. 103 W.	Not very good.
Flat Rock Spring	SW. ¼ sec. 26, T. 3 N., R. 103 W.	Good water, but small flow.
Iron Spring	In Chase Gulch, NW. ¼ sec. 20, T. 2 N., R. 101 W.	
Three Springs	At old Mobley post-office, sec. 34, T. 4 N., R. 100 W.	Good water.
Box Elder Spring	Sec. 8, T. 3 N., R. 100 W.	
Skull Creek	At Jones's ranch, sec. 1, T. 3 N., R. 101 W.	Do.
Red Wash Creek	Sec. 2, T. 3 N., R. 102 W.	
Willow Creek	Sec. 12, T. 3 N., R. 103 W.	Camping site and stream: good water.
Small stream	Sec. 35, T. 4 N., R. 104 W.	Good water.
Cliff Creek	K ranch, sec. 23, T. 4 N., R. 104 W.	

Beyond the southern and southeastern margins of the district here described, springs and headwaters of streams containing excellent water are found in the wooded slopes close up under the Cathedral Bluffs. The upper courses of the various forks of Douglas Creek are fresh and clear at a distance of 30 miles or more above Raven Park.

To the north, along the southern foot of Blue Mountain, as indicated on the map (Pl. I), there are numerous supplies of good fresh water, though usually in springs or streams of small volume. These have long furnished the excellent camping sites that lie along the old Uinta trail, which follows the valley from the Yampa and White River territory into Utah, forming a part of the route through this country to Salt Lake City. These waters are derived from the various sandstone strata in the older formations that flank the high plateau. They can be readily traced to the points where they issue from these strata in the form of springs, but in their lower courses they dry up soon after reaching the open prairie and valley lands.

Above Jones's ranch on Skull Creek, in the NE. ¼ sec. 1, T. 3 N., R. 101 W., a good flow of water issues from the upper beds of the Carboniferous sandstone, which underlies the brilliantly banded strata of the Midland Ridge escarpment. These waters are rather strongly charged with iron and sulphur, but were found very agreeable to the taste by comparison with the muddy water of the river below.

Box Elder is a camping site situated on the main wagon trail in the middle of the north side of sec. 8, T. 3 N., R. 100 W., about 2 miles southeast of Jones's ranch. A spring of good water is said to issue from the hogback ledges about half a mile above this place.

At Three Springs, which is east of the area shown on the map, on a minor fork of Wolf Creek, in sec. 24, T. 4 N., R. 100 W., the water ssues from the "White Cliff" sandstone (Jurassic) capping the rilliantly banded strata of the Midland Ridge escarpment. This s a well-known locality to the old settlers and travelers of the region. A ranch, formerly the post-office Mobley (now discontinued), is ituated by one of the springs. The springs lie north of the main ast-west route of travel, being about 2½ miles from the Yampa River-Utah trail. The approach from Wolf Creek valley is over a omewhat rough and rocky wagon trail, which also continues northvard and is one of the routes of access to the summit of Blue Mounain. The water is clear and cool and flows with very good volume rom several of the seeps that issue along the hillside within a disance of perhaps half a mile.

A group of springs is also found in the NE. ¼ sec. 2, T. 3 N., R. 102 W., in the west or main fork of Red Wash, at the point where hat stream crosses the same Jurassic sandstone ("White Cliff") from which the water is derived at Three Springs. The lowest spring of this group is one of considerable size and flow and is strongly charged with iron. From these springs water flows down the channel of Red Wash for only a short distance, soon sinking and drying up, except in wet weather.

The springs next west of Red Wash are those that form the headwaters of Willow Creek, in the SE. ¼ sec. 12, T. 3 N., R. 103 W. Here also the water issues from the "White Cliff" (Jurassic) sandstone, as at Three Springs and on Red Wash. It gathers in two small branches in the valley north of the Dakota hogback, uniting into a single stream of some little volume as it crosses the wagon road, but sinking soon after it passes out into the valley below.

West of Willow Creek the next spring water found along the Uinta trail is a small stream issuing from behind the Dakota hogback 2 miles south of the K ranch and near the Colorado-Utah State line, n the SE. ¼ sec. 35, T. 4 N., R. 104 W. Here also the water is derived from the Jurassic sandstone already referred to. This stream is very feeble in dry weather, often becoming of very small low during the day and regaining a somewhat stronger volume at night. It runs but a short distance out into the valley, however. before it sinks and its channel is normally dry.

At the K ranch one of the main branches of Cliff Creek contains sufficient water to irrigate a small field. The water is ponded in a small reservoir near the house and probably would flow for a considerable distance down the main creek channel were it not diverted. A more northerly fork of Cliff Creek lying near the escarpment named on the older maps as Section Ridge is said also to contain water.

RAIN WATER.

So far as is known to the writer no attempt has ever been made to save the rain water or snow water for domestic use. This is, however, accomplished in a natural way and is occasionally found to serve a very useful purpose. The back slopes of the cuesta or dip-slope ridges surrounding Raven Park are in many places capped by bare ledges of heavy-bedded massive white sandstone. Irregularities in these nearly horizontal beds retain the rain water of the summer showers, which frequently form innumerable pools, some very large and deep, in firmly inclosed rock basins. One of these pools situated in the ledges near the road from Rangely to the K ranch is used as a camp or watering stop by travelers if they are so fortunate as to be acquainted with its location.

ARTESIAN WELLS.

Of the wells that have been driven in the Rangely field none have encountered water in the Mancos shale, and as yet none have penetrated far enough to reach the Dakota sandstone, which is so commonly known to be a water-bearing formation under favorable conditions in other localities. It is reported that water was struck at a depth of 80 feet in the Requina oil well No. 2, which is situated close to the channel of Stinking Creek, and probably encountered an underflow of that stream. The drillers' reports state that this water was found "at the base of the adobe, in a bed of gravel overlying the shale bed rock." It is therefore assumed that the body of the Mancos shale is without water.

The possibility of obtaining artesian flow in Raven Park was suggested by White in the Hayden reports, but it now seems clear that he far underestimated the depth of the Dakota sandstone in that field. The structural conditions on which he based his estimate are apparently favorable, and such artesian flow might be available if the depth of the water-bearing stratum were not so great. Furthermore, the beds which are now seen to be the best water carriers at the springs along the foot of Blue Mountain and which occupy the most favorable positions as catchment areas on the flanks of that mountain are stratigraphically much lower than the Dakota sandstone and it would probably be impracticable to reach them by drilling from any point within the park. Although the chances that these sandstones below the Dakota may contain an artesian water supply are considered excellent, it is not at all certain that a similar flow would be found also in the Dakota beds. On the other hand, in spite of the meager catchment exposure of that formation and its apparent barrenness of springs along its outcrop it may possibly accumulate a sufficient volume of underground water to establish an artesian flow if reached by boring in the lower park lands.

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O

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DEPARTMENT OF THE INTERIOR
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THE CLAYS OF ARKANSAS

BY

JOHN C. BRANNER

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PREFACE.

By E. C. Eckel.

The following report on the clays of Arkansas was prepared by Prof. John C. Branner, while State geologist of Arkansas, for publication by the State Survey. The work of the organization was unexpectedly discontinued, leaving no provision for the publication of this report. Under the circumstances Professor Branner offered the manuscript for publication as a bulletin of the United States Geological Survey. As some years have elapsed since the original preparation of the manuscript, it has been necessary to bring up to date, so far as possible, the commercial and statistical data included in the report. Advantage has also been taken of recent Survey work in Arkansas to introduce later observations on the geology of certain districts. Mr. A. F. Crider has accordingly revised the sections on the geology and clay industries of the southeastern counties, while Mr. E. F. Burchard has revised the discussion of the Paleozoic clays and of certain areas in northwestern Arkansas, with a view chiefly to bringing the nomenclature into accordance with present Survey usage.

THE CLAYS OF ARKANSAS.

By JOHN C. BRANNER.

CHAPTER I.

TOPOGRAPHY AND GEOLOGY.

GENERAL FEATURES.

The broader topographic and geologic features of Arkansas are not local and characteristic but are rather portions of several physiographic divisions which find completed expression in areas beyond the borders of the State. Nearly all that part of the State lying northwest of a line drawn diagonally across it from northeast to southwest (from Randolph County to Little River County) is comparatively elevated, and is divided by the Arkansas River valley into the Ozark Plateau (including the Boston Mountains) on the north and the Ouachita Mountain region on the south. This northwestern portion is underlain by limestones, sandstones, and shales, which are approximately horizontal in the Ozark region, broadly folded in the Arkansas Valley, and highly folded and distorted in the Ouachita Mountains.

The Ozark Plateau region north of the Boston Mountains is deeply dissected by stream erosion. Its topography is therefore rugged, but the local elevations rise to the same general level. In the Boston Mountain region, which overlooks the plateau from an irregular northward-facing escarpment 500 to 700 feet above it, the topography is largely of the terrace and escarpment type, being developed on sandstones and shales. Stream dissection has made this area also very rough and broken.

The Arkansas Valley represents a worn-down plain. Low residual hills and ridges rise above it, and its streams flow in valleys cut below the general level.

Studies of the Ouachita Mountains by J. A. Taff[a] show that the uplift of this range involves a thickness of nearly 5 miles of rock.

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[a] Taff, J. A., Structural features of the Ouachita Mountain Range in Indian Territory: Science, new ser., vol. 11, No. 266, Feb. 2, 1900, pp. 187-188.

The structure is Appalachian, and the massive sandstone and novaculite ridges, primarily arched by folding and compression, have become accentuated by the more rapid weathering of the upturned edges of interstratified shales until great contrasts of relief have resulted. The anticlinal ridges of the Ouachitas trend nearly east and west, are roughly parallel, and rise 500 to 1,000 feet above the intervening valleys, or to altitudes of 1,600 to 2,100 feet.

Bordering the plateau region on the southeast and extending eastward beyond the borders of the State across the Mississippi Valley and southward to the Gulf of Mexico is a lower belt, underlain by younger, softer strata of marls, chalks, clays, sands, and gravels. Low altitude and slight topographic relief characterize this portion of the Gulf Plains. Crowleys Ridge, in the northeastern part of the State, is a remnant of a once extensive plain that stood at a level slightly higher than the present ridge. The slope of the whole is gulfward, and the plain is trenched by many broad, shallow valleys bordered by terraces with steep escarpments.

The older rocks are of Paleozoic age, ranging from early Ordovician sediments, through the Silurian and Devonian, to those of the later Pennsylvanian epoch of the Carboniferous period. The newer deposits represent interrupted sedimentation, beginning with the early Cretaceous and including Tertiary and Quaternary deposits.

Besides the sedimentary deposits certain small areas of intrusive rocks occur at Fourche Mountain, south of Little Rock, and at Magnet Cove, near Hot Springs. These rocks have been studied and described by the late J. Francis Williams,[a] and the areas near Little Rock which contain bauxite have been described by the writer,[b] but were afterward remapped by C. W. Hayes.[c] These rocks consist mainly of elæolite syenite, popularly termed granite, and were intruded into the sedimentary rocks probably late in Cretaceous time.

ORDOVICIAN SYSTEM.

The Ordovician beds are the oldest sedimentary rocks certainly recognized in Arkansas. They consist of a thick series of magnesian limestones, sandstones, siliceous limestones, and cherts, and cover all or portions of the following counties in northern Arkansas: Randolph, Lawrence (western half), Independence (northern part), Sharp, Fulton, Izard, Stone (northeastern part), Baxter, Marion, Boone, Searcy (northeastern part), Newton (northern part), Carroll (northwestern part), and small portions of Benton and Washington.

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[a] Williams, J. Francis, The igneous rocks of Arkansas: Ann. Rept. Geol. Survey Arkansas for 1890, vol. 2, 1891.

[b] Branner, J. C., The bauxite deposits of Arkansas: Jour. Geology, vol. 5, 1897, pp. 263-289.

[c] Hayes, C. W., The Arkansas bauxite deposits: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, pp. 440, 446, and 454.

These rocks are, for the most part, nearly horizontal, but show gentle folds at some places, while at others they are somewhat faulted.

Ordovician rocks appear also in an area south of the Arkansas River Valley, in the Ouachita Mountain country. In this region they include the novaculites and the rocks immediately underlying them. They are exposed in portions of Pulaski, Saline, Garland, Hot Spring, Montgomery, Polk, and Pike counties.[a]

The Ouachita Ordovician rocks are composed chiefly of novaculites and shales. They have been pressed together from the north and south, so that the beds have been thrown into a series of sharp east-west folds. After they were folded erosion cut away the tops of the arches, leaving the hard novaculites as prominent ridges over the whole area.

SILURIAN SYSTEM.

Silurian rocks are known only in the northern part of the State. They rest conformably on beds of Ordovician age, but have been recognized at only a few places—in the region just west of Batesville and at points as far west as St. Joe, in Searcy County. These Silurian beds are limestones, at some places overlying a bed of shale of probable Ordovician age. The areas of these beds are too small to be represented on the accompanying map (Pl. I), so they have been included with the Ordovician.

DEVONIAN SYSTEM.

The Devonian period is represented by beds of variable character—in some places a black shale, in others a sandstone containing phosphate nodules. The thickness of the shale ranges from a few inches to 70 feet; that of the sandstone ranges from 5 to 75 feet. These rocks are known only in northern Arkansas, where they follow the contact between the Silurian and Carboniferous rocks from near Batesville westward to the vicinity of St. Joe, in Searcy County. They have been recognized also along White River northeast of Fayetteville, and in the northwest corner of the State, at Sulphur Springs, where both shale and sandstone are well developed. Although the phosphatic nodules occur sparingly in places in the lower few inches of the overlying basal Mississippian limestones, there was probably a break in sedimentation between the two formations, and the nodules have been reworked into the younger beds from the débris of the older. This formation also is so limited that it is mapped with the Ordovician rocks.

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[a] A report on this area by L. S. Griswold appears in Ann. Rept. Geol. Survey Arkansas for 1890, vol. 3, 1891.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

Several divisions of the Mississippian rocks have been recognized in Arkansas. Brief mention is made of each of these owing to the important bearing which the limestones and shales have on the production of clays and, consequently, the necessity for guidance in identifying the formations and in determining their areal distribution.

Boone formation.—The Boone formation consists in the main of a series of cherty limestones and cherts that has been known as the "Boone chert," a name given to the series on account of its wide distribution in Boone County. Below these over a large area in the northern part of the State lies the St. Joe limestone member of the formation, a well-marked bed of gray or pink crystalline limestone, which is the basal Carboniferous bed. It is easily recognized by its color, texture, and its marked contrast with the beds that usually underlie it. This limestone forms an almost unbroken outcrop from the vicinity of Mountain View, in Stone County, to the State line near Seligman, Mo. Where the cherts contain much limestone they form, on decay, a very fertile soil. The fine farms of Boone County about Harrison, Valley Springs, Belfonte, and Rally Hill are on the "Boone chert." This formation covers the greater part of Benton County and the northern and western parts of Washington County. Where the chert is comparatively free from limestone beds the soil is too meager for agriculture and forms the "flint hills" of western Carroll and northern Madison counties and the watersheds north of Marshall and southwest of Rush Creek, in Marion County, and the hilltops about Elixir Springs, Boone County, and Doddsville, Marion County.

Moorefield shale.—In the vicinity of Batesville there is a bed of shale lying on the Boone formation. It is well exposed around Moorefield, from which place it is named. In that locality it has a thickness of from 50 to 75 feet. To the west, at Marshall, it is not over 35 feet thick, and evidently it does not extend much farther westward. The shale has a light grayish or bluish color and is very friable. In places it is sandy. It is not important, but is described here in order to give the full sequence of rocks in the section along the northern border of the Boston Mountains.

Batesville sandstone.— Next above the Moorefield shale is the Batesville sandstone, so named from the town of Batesville, which is built on this sandstone. It is present along the base of the slopes of the isolated hills and mountains north of the Boston escarpment, in Independence, Stone, Searcy, Newton, Boone, Carroll, Madison, Washington, and Benton counties. The rock is coarse, cream-colored to brown, often false bedded, and in some places contains beds of shale interstratified with sandstone. A light sandy soil results from its disintegration. It serves as an excellent reservoir, for the wells that penetrate it usually find in it an abundance of good soft water.

Fayetteville formation.—Next above the Batesville sandstone lies a formation consisting principally of black or dark-gray carbonaceous shale, at many places thinly laminated. Near its base there is generally a thin bed of hard, dark gray or blue limestone, while its middle part commonly grades from a sandy shale to a true sandstone, and where the sandstone phase predominates this portion of the formation is distinguished as the Wedington sandstone member. The shale is well developed in the valley of West Fork of White River near Fayetteville, from which it is named, and the Wedington sandstone member is particularly prominent southwest of Fayetteville, in Wedington Mountain, where it attains a thickness of 150 feet—perhaps one-half the total thickness of the formation. The softness of the shale causes it to erode so easily that its outcrop is usually marked by a valley. Where exposed, the shale disintegrates readily and forms a black and fertile soil. The composition of the unweathered shale renders it suitable material for brick making. The shale beds are practically constant from the Oklahoma line to Sulphur Rock, east of Batesville.

Pitkin limestone.—Above the Fayetteville shale or the Wedington sandstone in northern Arkansas there is nearly everywhere a thin, inconspicuous bed of limestone—the Pitkin—characterized by screw-like stems of the fossil bryozoan *Archimedes*. This formation is regarded as the highest in the Mississippian series.

PENNSYLVANIAN SERIES.

Morrow formation.—Under the name Morrow formation are included several beds of limestone, sandstone, and shale which vary much in thickness, arrangement, and character, and are of but little topographic prominence. These beds lie just below the sandstone of the "Millstone grit" series of the Arkansas Survey, and, as a rule, form the middle part of the escarpment of the Boston Mountain range. South of Batesville, near Jamestown, these beds have a total thickness of about 200 feet, while in a section in the north face of the mountains, south of Fayetteville, they are about 400 feet thick. The soil derived from them is highly fertile, but the land, being for the most part very precipitous, is so badly located for agricultural purposes that it is not generally cultivated. It possesses, however, a fine timber growth and several available limestone beds.

Winslow formation.—The Winslow formation lies upon the Morrow formation and makes the summit and southern slopes of the Boston Mountains, except in the deeper ravines where older rocks have been exposed. Rocks of this formation also occur on the tops of the outliers immediately north of the Boston Mountains.

The formation consists of beds of sandstone and shale, with a few thin local layers of limestone. The sandstone beds range in thickness from 3 feet to more than 50 feet. One of these beds, and in places two, near the base of the formation, are conglomeratic, containing waterworn quartz pebbles of small size. These gritty beds at and near the base of the Winslow formation were described by the Arkansas Geological Survey in the report on Washington County as the "Millstone grit." The shales, which constitute probably 75 per cent of the formation, are as a rule black and carbonaceous, though less so than the shales of the Morrow formation. Coal occurs within this formation but only in beds too thin to be profitably worked. The Winslow formation in the Boston Mountain region extends up to the base of the series of rocks that contain the workable coal beds in the Arkansas coal field, and its total thickness is estimated to be more than 1,500 feet.

South of the Boston Mountains the Winslow formation is represented in a part of the thick series of sandstones and shales that underlie the coal-bearing rocks in the Arkansas coal field. This series of rocks was referred to in the publications of the Arkansas Survey as the "Lower or Barren Coal Measures." The uppermost formation in this series has been described in the report of the Arkansas coal field [a] and in publications on the Indian Territory coal field as the Atoka formation. This formation in Oklahoma and Arkansas ranges in thickness from 3,000 to probably 5,000 feet. Beneath the Atoka formation there are other formations of sandstone and shale of probable Pennsylvanian age, aggregating 12,000 to 15,000 feet in thickness.[b] These rocks make the rugged country of the Ouachita Mountain region south of the Arkansas coal field, and the Arkansas River Valley east of the coal field and south of the Boston Mountains.

In the study of the fire clays and clay shales of the State the shale beds of the "Lower or Barren Coal Measures," as well as of similar beds in the productive coal-bearing rocks, are of much importance. In the region of the Boston Mountains and in the lower region of similar formation on the east the rocks of the "Lower Coal Measures" lie flat, or approximately so, and their outcrops and distribution are thus very simple and are easily traced. In the region south of this area of horizontal beds, however, the same rocks are thrown into folds that become more and more abrupt toward the south. The upper portions of these folds are worn away by erosion, and the sandstones are left as ridges while the soft beds of shale are degraded.

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[a] Bull. U. S. Geol. Survey No. 326, 1907.

[b] Branner, J. C., Thickness of the Paleozoic sediments in Arkansas: Am. Jour. Sci., 4th ser., vol. 2, 1896, pp. 229-236.

The soil derived from the rocks of the "Lower Coal Measures," being deficient in lime and in some places rather thin, is only moderately fertile.

Hartshorne sandstone.—The Hartshorne sandstone lies at the base of the productive coal-bearing rocks of the Arkansas coal field. It is known to have a great areal extent, and is found cropping out around the edges of the coal-bearing rocks from the east end of the Arkansas coal field westward into Oklahoma. It is 100 to 300 feet thick, and contains minor beds of shale in its central and upper parts.

McAlester group.—Above the Hartshorne sandstone there is in the productive coal-bearing rocks a series of shales and sandstones with a number of beds of workable coal. The McAlester group is divisible into three formations—(1) a lower, known as the Spadra shale, consisting of three or more beds of coal and minor strata of sandstone; (2) a middle, called the Fort Smith formation, composed chiefly of sandstone and shaly sandstone beds with one or more workable beds of coal; (3) an upper, described as the Paris shale, consisting partly of beds of sandy shale with some sandstone and one or more workable beds of coal. These formations of the McAlester group are described in the report on the Arkansas coal field.[a] The Spadra shale is 400 to 500 feet thick, the Fort Smith formation 375 to 425 feet, and the Paris shale 600 to 700 feet.

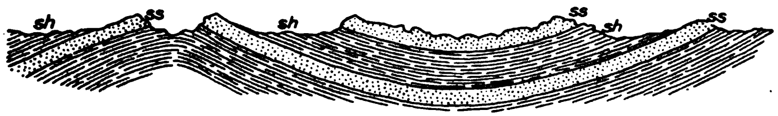

Fig. 1.—Ideal section across folds in the Carboniferous rocks of western Arkansas. *sh*, Shale; *ss*, sandstone.

Savanna formation.—Overlying the McAlester group there is in the productive coal series a formation consisting of several sandstone members separated by shales. This is known as the Savanna formation. It occurs in Arkansas only in the tops and upper slopes of Poteau, Sugarloaf, Short, and Magazine mountains. That part of the Savanna exposed in Arkansas is estimated not to exceed 1,000 feet, and constitutes approximately the lower two-thirds of the formation.

The rocks of this formation, as well as the other rocks of the productive coal series, are all more or less folded, so that the shale outcrops depend on the character and direction of these folds and can therefore be determined only after a study of the structure of the region. It can be said, however, that the shale outcrops generally lie in the valleys parallel to the ridges, so that a cross section of the region would show the rocks to have the relations shown in fig. 1.

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[a] Bull. U. S. Geol. Survey No. 326, 1907.

OCCURRENCES PRECEDING THE CRETACEOUS.

Deposition of the rocks from the Ordovician beds to those of the Pennsylvanian took place over the same general area. The exposures of the Mississippian and the rocks below that horizon have resulted from the erosion or removal of rocks that once overlay them. Had the entire area of the State continued submerged during Mesozoic time, Triassic, Jurassic, and Cretaceous rocks would most probably be found to overlie the Carboniferous formations. The distribution of the Cretaceous rocks, however, shows that at the close of Carboniferous time a large area became dry land, and that the shore of the Cretaceous ocean crossed the southwestern part of the State somewhere below the northern border of the Cretaceous area shown on the geologic map (Pl. I).

CRETACEOUS SYSTEM.

Rocks of Cretaceous age occur in but a small portion of the State. They are present, concealed in some places by later deposits, in a roughly triangular area south of the Ouachita Mountains and west of Arkadelphia. The Tertiary-Cretaceous border lies slightly southeast of the St. Louis, Iron Mountain and Southern Railway between Arkadelphia and Texarkana. The rocks are not folded or bent, but dip to the southeast at a low angle. They are usually unconsolidated, contain considerable calcium carbonate, and form, on decay, a very fertile black soil. The Cretaceous deposits have been described in detail,[a] so that they need not be further mentioned here, except to call attention to the fact that later observations have shown that the Arkadelphia shale at Arkadelphia is Cretaceous and not Tertiary, as was originally supposed. Cretaceous rocks have also been recognized at a few places north of Little Rock.

TERTIARY SYSTEM.[b]

Clays, sands, and gravels of Tertiary age cover the greater part of eastern and southern Arkansas. In the rocks of this age and near their base, at Benton and near Malvern, there are valuable beds of potter's clays. These beds dip gently to the southeast. They are all more or less sandy, and but few of them are hard and consolidated. At the lignite mines of Ouachita County, however, some of the sands are indurated to very compact sandstones, and at some places in Crowleys Ridge they form the hardest of quartzites. Though the

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[a] Hill, R. T., Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2, pp. 66–174; also Taff, J. A., The chalk of southwestern Arkansas: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, pp. 687–742; Branner, J. C., The cement materials of southwest Arkansas: Trans. Am. Inst. Min. Eng., vol. 27, 1898, pp. 42–63.

[b] For details of the Tertiary geology of the State see The Tertiary geology of southern Arkansas, by G. D. Harris: Ann. Rept. Geol. Survey Arkansas for 1892, vol. 2, 1894.

Tertiary is widespread in the eastern and southern parts of the State, it is at many places overlain by a thin coating of Quaternary deposits, so that the true character of the Tertiary beds is more or less obscured.

The lignites exposed along Saline and Ouachita rivers, the marls exposed at White Bluff and Red Bluff on Arkansas River, and the shell marl on Little Crow Creek, St. Francis County, are all Tertiary. The hard sandstones in Crowleys Ridge about Gainesville are of the same age.[a]

QUATERNARY SYSTEM.

A thin sheet of sedimentary materials, consisting of sands, clays, and gravels, cover the Tertiary area of the State and some of the adjacent Paleozoic rocks. The country lying north of Arkansas River and east of the Paleozoic hills belongs to the Quaternary. The lowest strata exposed in Crowleys Ridge belong to the Eocene. All the river bottoms are of recent origin, while the loess capping Crowleys Ridge and likewise the river terraces and second bottoms of all the important streams belong to the Pleistocene. The waterworn materials that cover the foothills of Lawrence, Independence, Pulaski, Saline, Hot Springs, Clark, Pike, Howard, and Sevier counties are of late Tertiary or Pleistocene age.

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[a] Call, R. E., The geology of Crowleys Ridge: Ann. Rept. Geol. Survey Arkansas for 1889, vol. 2, 1891.

CHAPTER II.

CHARACTER, ORIGIN, OCCURRENCE, AND USES OF ARKANSAS CLAYS.[a]

CLASSIFICATION OF THE CLAYS.

No sharply defined classification of the common clays is altogether satisfactory, for clay is not a definite compound nor a well-defined mineral species, and the qualities and values of clays depend upon physical and chemical properties which vary within wide limits, so that the various kinds of clay grade imperceptibly into one another. The clays of this State may be classified, however, with reference to their mode of formation, as: (1) Residual clays, (2) clays of mechanical origin, (3) clays and kaolins of chemical origin, and (4) bauxite. They will be briefly discussed in this order.

RESIDUAL CLAYS.

Clays and kaolins are chiefly secondary products derived either directly or indirectly from feldspathic rocks—that is, from rocks composed either entirely or largely of the mineral feldspar, such as granite, syenite, and gneiss. The feldspathic rocks may be either eruptives—that is, rocks injected in a molten condition from below into or through crevices in the earth's crust—or they may be the crystalline rocks that underlie our oldest sedimentary rocks. Whenever and wherever these rocks occur near the surface they decay—many of them very slowly—and form kaolins or clays containing more or less impurities. When the rocks contain little else than feldspar, or when the minerals that would stain or otherwise injure kaolin are removed in solution, they form, on decomposition, kaolin of more or less value; but when they contain considerable quantities of iron, manganese, or other discoloring impurities they form clays of various colors. Such clays and kaolins are said to be derived directly from feldspathic rocks.

The precise process of the alteration of the solid syenites of the Fourche Mountain region to kaolins and clays is illustrated by the following analysis. The column marked "blue syenite" shows the composition of the original unaltered rock, the column marked "decomposed blue syenite" shows the chemical alteration of this same rock in process of decomposition, while the column headed "kaolin" shows the last stage of alteration to kaolin.

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[a] Persons wishing to consult other works on clays will find a bibliography of the subject in Bull. U. S. Geol. Survey No. 143, 1896; a second edition of that bibliography was published by the American Ceramic Society at Columbus, Ohio, in 1906.

Analyses of pulaskite (blue syenite) and its decomposition products.

[Brackett & Smith, analysts.]

Constituents.	Blue syenite.	Decomposed blue syenite.	Kaolin.
Silica (SiO_2)	60.03	50.65	46.27
Titanium (TiO_2)	....	.06	....
Alumina (Al_2O_3)	20.76	26.71	38.57
Ferric iron (Fe_2O_3)	4.01	4.87	1.36
Ferrous iron (FeO)	.75	....	....
Lime (CaO)	2.62	.62	.34
Magnesia (MgO)	.80	.21	.25
Manganese (MnO)	Trace.	....	....
Potash (K_2O)	5.48	1.91	.23
Soda (Na_2O)	5.96	.62	37
Phosphorus (P_2O_5)	.07	....	....
Water (H_2O)	.59	8.68	13.61
	101.07	94.33	101.00

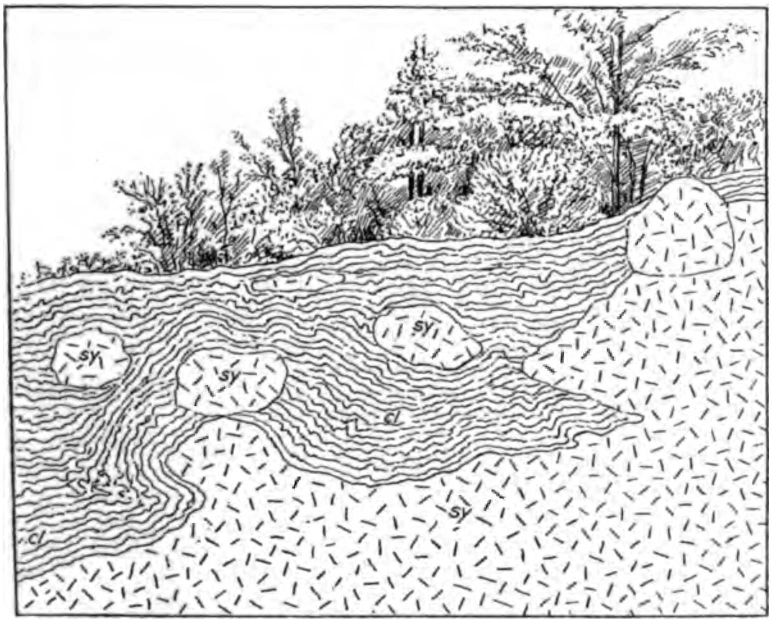

FIG. 2.—Residuary clay formed by decomposition of syenite in place, in railway cut 3 miles south of Little Rock. *sy*, Syenite; *cl*, clay.

It should be noted that the changes in passing from syenite to kaolin consist chiefly in the absorption of water, the removal of the more soluble materials, such as lime, potash, and soda, and the consequent increase of the percentage of alumina.

This blue syenite is at many places traversed by cracks or joints that break it into great angular fragments. Water charged with organic acids which are derived from decaying vegetable or other organic matter, on penetrating these cracks causes the rock to decay, the decomposition processes attacking the masses at first along these openings and then extending inward until only a rounded bowlder is left; later still the whole mass is converted into clay, the soluble parts of the rock having been washed out by the percolating water. Vast quantities of clays are formed in this way by the decay of the crystalline rocks, and no doubt such decay has been going on since the crust of the earth began to harden.

Fig. 2, sketched in the railway cut 3 miles south of Little Rock, illustrates this method of forming clay, the clays at that place having been derived directly from the syenites by decomposition.

Bruno Kerl[a] holds that feldspar may even be decomposed by water alone at high temperatures and under strong pressure, yielding clay, silicate of potash, and silicic acid. Carbonic acid may produce similar decomposition at ordinary temperatures and without pressure.

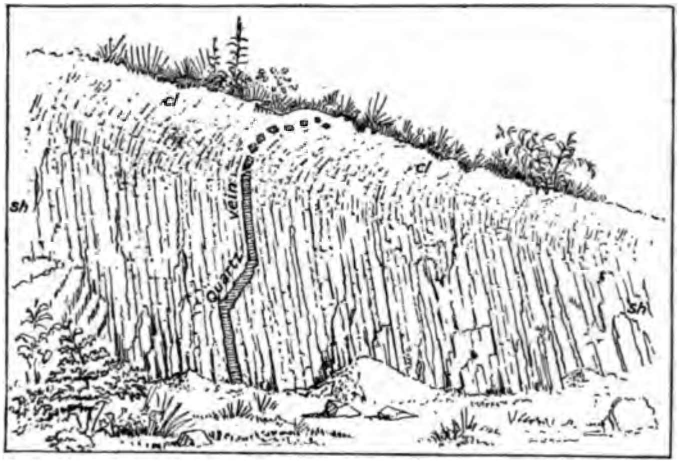

FIG. 3.—Shales decaying at the surface in railway cut at Little Rock. *sh*, Shale; *cl*, clay formed by decomposition of shale in place.

Fig. 3 is a sketch made in the railway cut about a mile west of the union depot at Little Rock. The clays at the top of the ground here are simply the decayed upturned edges of the shales exposed in the railway cut. Deeper down the shales are compact and undecomposed.

The thin vein of quartz in the shale evidently once passed upward into the extension of the shales, but as the shales decayed and formed a soft clay the quartz, not being so readily attacked by weathering agents, simply broke into irregular fragments and remained in the clay or shale after it was decomposed. Any other insoluble materials in the shale, such as sand, would thus be left as an impurity or grit in the clay.

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[a] Handbuch der gesammten Thonwaarenindustrie, Braunschweig, 1879, p. 29.

The clay in this place is derived directly from the shale. But the shale itself is an argillaceous rock which was originally made from clays and sediments that washed down from land where some of the old feldspathic rocks were decaying or had decayed. This residuary clay is thus derived directly from shale, but indirectly from feldspathic rocks.

Fig. 4 shows the derivation of clay from limestone by decomposition, the lime of the rock being dissolved out and carried away, the clay, iron, sand, and whatever insoluble impurities the rock contained being left behind. This clay is of a deep red color. It contains some fragments of the limestone from which it is derived—small pieces not yet completely decomposed. This limestone contains nodular pieces of chert or flint, and as these do not decay, or at least do not decay so rapidly as the limestone, they are left as loose pieces in the clay. The clay in this case comes from the impurities in the limestone, and these impurities, in so far as they form clay, were deposited as an argillaceous silt with the calcareous material that forms the limestone. This will serve to explain at once the origin of the clays of some limestone regions and the great blanket of clay found over most limestone regions, as well as that found in caves and in crevices and fissures in limestones.

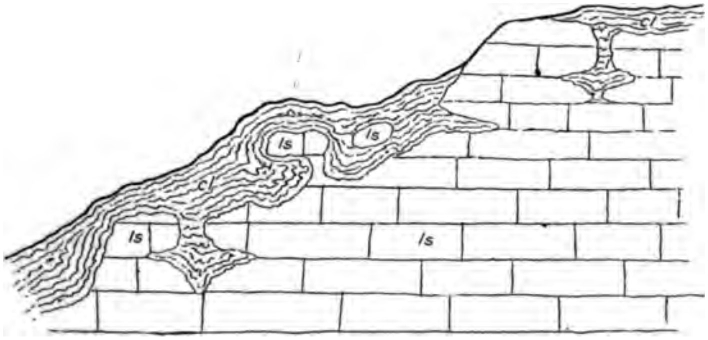

Fig. 4.—**Section** on Dry Creek, Carroll County, showing formation of clay by decomposition of limestone. *ls*, Limestone; *cl*, clay.

Clays thus formed and lying where they originated are the residue from the decay of some hard rock, and are therefore called residuary clays. Other illustrations might be given to show how clays are derived from other kinds of rocks than those mentioned, but these are enough to show what is meant by residuary clays. The decomposition of rocks and the formation of residuary clays may be seen in almost every part of the elevated portion of the State.

It is evident that the clays derived from any of the rocks mentioned must vary more or less among themselves, according to the amount and character of the insoluble contents of the rocks from which they are derived. Wherever these residuary clays are exposed at the surface they are usually still further modified by weathering and by organic agencies. When they are washed into streams, sorted by the currents, and deposited again they form what are known as redeposited clays.

CLAYS OF MECHANICAL ORIGIN.

Clays may be produced by grinding to a fine powder any rock that will produce clay upon decomposition. When thus pulverized some of these rocks, possibly all of them, become more highly hydrated or take up more water of crystallization,[a] a change which is probably explicable, in part at least, upon the theory that much more rapid decomposition is produced by finely dividing the material so as to expose a very large surface to decomposing agencies. The trituration of rock fragments dashed against one another either by the current of a stream or by the action of waves wears the fragments round, forming cobblestones, pebbles, sand, and mud. More mud than sand is formed in this operation—in other words, the greater part of the material passes almost directly from the condition of a solid rock to that of a clay. This clay is carried along by the water until the current is checked, when it gradually sinks to the bottom and forms a bed or layer. But whether the argillaceous sediments carried into the sea by streams are of mechanical or chemical origin, they all go to form new beds of clays over the bottom of the sea. All parts of the earth's surface above the ocean's level are being gradually cut down by the slow but never-ceasing processes of weathering and erosion and are carried away either in chemical solution or in mechanical suspension. In this process of degradation the heavier materials are left behind for further disintegration, while the lighter—that is, the clays and fine sands—are carried away by streams. This mechanical separation by water goes on constantly, and during the eons of geologic time the results of such agencies have accumulated until they have ultimately produced an impressive and almost incredible total.

KAOLIN.

The distinction between clay and kaolin, except in a mineralogical sense, is an arbitrary one, for the two grade imperceptibly into each other. Both kaolin and clay are derived chiefly, either directly or indirectly, from feldspathic rocks by decomposition. Kaolin is composed of silica, alumina, and water, usually with a little impurity, while clay has the same constituents, but its impurities form a larger percentage of its composition. These impurities are often in the form of free silica or fragmentary quartz, and this being anhydrous an analysis of the material shows a smaller percentage of water than is found in the purer clay or kaolin. Thus, while kaolin usually contains about 12 per cent of water, the clays have less than 8 per cent.[a]

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[a] Daubrée, A., Géologie expérimentale, p. 252.

Kaolin deposits may originate in three ways—(1) by the alteration of feldspar in place; (2) by chemical action other than the ordinary alteration of feldspar, as illustrated by rectorite; (3) by the washing down and redepositing of kaolin formed in place. The great bulk of our kaolins, however, are derived directly from feldspar. The process by which feldspar or feldspathic rocks are changed to kaolin is kaolinization. Syenite, which is generally known in Arkansas as "granite," is made up largely of feldspar, and when the feldspar decomposes, as it always does sooner or later, it forms kaolin. The other ingredients of the syenite, however, such as hornblende, mica, iron, pyrites, and quartz, remain in the residuary material, so that it does not form pure, clean kaolin, but is generally an impure clay. Below are analyses of feldspar, of a variety of Arkansas syenite, and of a syenite partly changed into clay.

Analyses of feldspar, syenite, and kaolin.

	Feldspar.[a]	Blue syenite.[a]	Decomposed syenite.[b]	Kaolin.[c]
Silica (SiO_2)	66.39	60.03	58.50	46.27
Alumina (Al_2O_3)	18.13	20.76	25.71	38.57
Ferric oxide (Fe_2O_3)	1.44	4.01	3.74	1.36
Ferrous oxide (FeO)	...	.75	...	...
Lime (CaO)	.16	2.62	.44	.34
Magnesia (MgO)	.06	.80	Trace.	.25
Potassium (K_2O)	8.51	4.48	1.96	.23
Soda (Na_2O)	5.36	5.96	1.37	.37
Phosphoric acid (P_2O_5)	...	.07	...	...
Water	.42	.59	5.85	13.61
	100.47	101.07	97.57	101.00

[a] From Fourche Mountain, Little Rock, Ark.
[b] From Pulaski County, railway cut 2 miles north of Sweet Home.
[c] From sec. 9, T. 1 S., R. 12 W.

These analyses show that in passing through the process of decomposition from a hard blue syenite to a kaolin the rock loses part of all its ingredients except alumina and water, which are proportionately increased; or perhaps it would be better to say that the removal in solution of some of the constituents leaves others predominant. The change from feldspar to kaolin goes still further, but the feldspar contains less iron and is therefore more liable to end in a clean white kaolin than is the ordinary rock.

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[a] Of course no reference is here intended to prophyllite or rectorite, which are hydrous silicates of alumina and contain less than 8 per cent of water. Those substances, however, are not likely to be mistaken for common clays.

POTTERY CLAYS.

By pottery clays is here meant such as are commonly used in the manufacture of crocks, jars, jugs, and churns at the potteries now in operation, and not the poorer kaolins that might be used for similar purposes. All the clays of the State that are or have been used for the manufacture of pottery are grouped here under the head of pottery clays, whether or not they are available for other and more important uses. The common pottery clays of Pulaski, Hot Spring, Saline, Clark, Hempstead, and Miller counties, and those in other of the southeastern and eastern counties of the State, are all of sedimentary origin and of Eocene or lower Tertiary age. They were laid down in nearly horizontal beds, which generally dip toward the southeast at a low angle, so that beds that outcrop at or near the Paleozoic highlands lie at depths that become greater toward the southeast. In nature these Tertiary deposits vary from coarse sands through earthy marls to fine plastic clays. Many of the clay beds contain impressions of fossil leaves and small sticks of wood—materials that evidently sank, with the clays that inclose them, to the bottoms of the swamps or lagoons that once covered this region.

While the pottery clays dip to the southeast and gradually descend to greater depths beneath the surface, the beds do not preserve throughout the characters they may display at a single exposure. It is a well-known fact in geology that sedimentary beds may vary in character and thickness from one point to another; indeed, they are even more liable to vary than to be constant in thickness and character. So while the pottery clays may be of uniform thickness and quality toward the southeast, or may even improve in quality and increase in quantity, it must not be inferred that this is proved. It is possible that they form lenticular masses; but in any case, those who would prospect for pottery clays within the Tertiary area of the State would do well to bear in mind their structural features and their possible variations.

Although sediments are deposited in approximately horizontal beds, the pottery clays about Benton and elsewhere in the Tertiary region of the State occur as fragmentary beds in isolated hills. After the Tertiary beds had been laid down they were elevated, so that from being soft muds and sands at the bottom of the sea or of lagoons they came to form "dry land." But all "dry land," or all of the crust of the earth that stands uncovered by water, is subjected to eroding agencies which cut it down and wash it away, leaving its surface scored and furrowed by gullies, ravines, and valleys. By this process the beds of former sediments are carried away, whether they be sands, gravels, or clays, while over the surface is spread out a thin covering of the less soluble or less portable material.

CLAYS FOR DRAIN TILES.

There is no lack of clay in this State available for the manufacture of good drain tiles. The light-blue clays through the country lying between Beebe and Kensett and thence to Judsonia, and between Kensett and West Point, in White County, are available for the manufacture of tiles. The clays about Brinkley, Monroe County, are well adapted to tile making. Along the western base of Crowleys Ridge in Phillips, Lee, and St. Francis counties, and on both sides of the ridge in Cross, Poinsett, Craighead, Greene, and Clay counties, these clays are abundant and of excellent quality. They abound also along Bradshaw and Terre Noir creeks in Clark County.

In the counties south and southeast of Little Rock clays available for tile making occur both as surface soils in the valleys (not alluvial) and in the widespread stratified Tertiary beds of the region.

In the hilly regions north of the Cretaceous and Tertiary area of the State drain tiles are not likely to come into demand except, perhaps, in the bottom lands, but wherever they may be wanted they can be made from the brick clays that have accumulated in the valleys.

Along the Petit Jean and Fourche le Fevre the surface soils of the lowlands are generally available for tiles. In the neighborhood of Arkansas River tile-making material may be found in abundance in the terraces of brown and reddish clays that lie just outside of the "second bottoms." Any of these clays will be improved for tile making if they are allowed to weather through a winter.

The demand for drain tiles has hitherto been so limited that but little work has been done in manufacturing them. Whatever benefits may come from the drainage of the soil are either unknown to the average landowner or are disregarded, while the expense of procuring tiling and draining has acted as an additional drawback to the custom of underdraining in places where it would be of great service. There can be no doubt, however, that many of the most fertile lands of the State of Arkansas that now lie unused could be brought under cultivation if they were only properly drained. The custom of underdraining must necessarily be adopted by our farmers in the near future, and when fairly tried it will soon prove its own importance on certain kinds of lands. It is especially true of the lowlands within the Quaternary area of the State. R. E. Call, who has paid especial attention to the Crowleys Ridge region, is of the opinion that thousands of square miles that now lie idle along White, Cache, L'Anguille, and Arkansas rivers can be brought under profitable cultivation by some system of underdraining.

BUCKSHOT CLAYS.

Character.—In many places in this State and at some places over a great many square miles, both in the Paleozoic highlands of the western part of the State and in the Tertiary and Quaternary lowlands of the east, there is a kind of clay, usually of an ashen color, but often mottled red, gray, and yellow, that contains great quantities of nodules of iron (limonite) varying in size from that of a pin head to that of a walnut. This is one of the soils known as "buckshot" land, a name doubtless given to it on account of the size and form of these nodules.[a] The nodules at some places lie along a broad but well-defined line at a uniform depth from the surface; in others their depth varies greatly; they may be on the surface or may lie as deep as 5 or 6 feet below.

Origin of the "buckshot."—The process by which these nodules are formed seems to be as follows: The iron was originally distributed through the uppermost bed of the surface clay. Vegetation growing and decaying on the surface furnished vegetable acids to waters that penetrated the soil and dissolved out the iron from the upper portions of the beds. As the iron-charged waters penetrated the clays the iron was precipitated at points a short distance below the surface to form the buckshot nodules. These nodules are never very abundant on hillsides or steep slopes,[b] but occur for the most part on gentle slopes and in the soils of the "slashes" or flat lands on which the water stands or has stood during wet seasons. The leaching of the iron from the upper beds of clay leaves them usually of a pale ashen or cream color, while the admixture of organic matter sometimes gives them a leaden color.

Carbonic acid is probably one of the most active agents in dissolving the iron from the surface soil and redepositing it at lower depths. But on descending with water through the upper layers, so long as water stands upon the ground, carbonic acid will not give up its iron. If it should pass downward the iron would remain in solution, and if it flowed away laterally the iron would be precipitated only when the water came near the surface. It therefore seems probable that this iron remains in solution until the wet grounds become dry, when it is precipitated by the evaporation of the water. As might be expected from the conditions under which these lumps of iron are formed, they vary in size and in their distance from the surface, and the bands in which they are arranged vary in thickness.

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[a] In Arkansas another kind of soil is also known as buckshot land. The latter is calcareous alluvial soil containing considerable clay. After being plowed the clods, on weathering, break into small cuboidal lumps, which appear to have suggested the name buckshot by their size rather than by their shape. This soil is usually very fertile, while that containing the limonite nodules is rather poor.

[b] At Forrest City a band of limonite nodules is exposed in a railway cut 43 feet below the surface. This probably represents the ancient soil cited by Chamberlin and Salisbury as underlying the loess. (See Call's report on The geology of Crowleys Ridge: Ann. Rept. Geol. Survey Arkansas for 1889, vol. 2, p. 159, and Pl. 1, fig. 2, p. 206.)

Uses.—In many parts of the State these lowland clays are used for making common bricks, but they are not very well adapted to such use. The iron lumps cause hard black spots in the bricks, and the clay is more or less troublesome to work by hand, for the nodules tear the hands of the brick molders and catch on the sides of the molds. These difficulties could be averted by crushing or screening the clay, but it is doubtful whether the expense of such a process would be warranted in making ordinary bricks.

It is of much importance to find that some of these lowland clays have been used successfully in the manufacture of Portland cement at Whitecliffs, in Little River County. In reply to inquiries about the clays employed, the secretary of the company, Mr. W. J. Kelly, kindly furnished the following information:

The first clay we used for making cement was taken from the SE. ¼ SE. ¼ sec. 35, T. 11 S., R. 29 W., on the west side of Little River, the analysis of which is as follows:

Analysis of cement-making clay mined on Little River near Whitecliffs.

SiO_2	72.64
Al_2O_3	13.91
Fe_2O_3	3.72
CaO	.20
MgO	.45
Total volatile	7.53

As this deposit is across the river from the works, we experimented with the clays on the east side of the river and found a bed of clay one-fourth of a mile south of the plant.

The bed of clay on this side of the river is several acres in extent and 16 feet thick in the SW. ¼ SW. ¼ sec. 36, T. 11 S., R. 29 W. The analysis of this clay is as follows:

Analysis of brick clay mined on Little River near Whitecliffs.

SiO_2	74.54
Al_2O_3	14.47
Fe_2O_3	1.79
CaO	.73
MgO	.41
Total volatile	6.26

Alkalies not yet determined.

From this clay we also made 2,000,000 red brick in 1897 and 1898. There is no stripping whatever, as the deposit starts at the surface. We have a narrow-gage railroad from the plant to the pit.

THE LOESS.

The loess constitutes the upper 30 to 90 feet of the higher portions of Crowleys Ridge from Dee post-office, in Craighead County, southward to Helena, in Phillips County. At Helena it attains its maximum thickness. Throughout the areas of its distribution, both in Arkansas and in other States, it usually contains large numbers of limy concretions, or puppets, which are highly characteristic of its soils.

Throughout the region it covers in Arkansas the loess may be readily recognized by its fineness and by its light-yellow or buff color. In certain localities it becomes slightly darker in color, possibly by reason of the presence of organic matter, or it may even be blotched with dark-brown and reddish colors. Close examination of these blotches reveals the fact that the color is due to a superficial coating of iron oxide on the individual grains.

This loess is especially suited to the manufacture of superior grades of brick. Care is necessary in its preparation for molding, however, and discrimination is required in respect to the mixture of soils from the neighboring hills. Where the soils of the hillsides are largely made up of sands and gravels derived from local outcrops of the Tertiary strata, as they are in some places about Jonesboro, Harrisburg, Gainesville, and Wynne, they are unsuited to the manufacture of good brick. At other localities, notably near Marianna, at Forrest City, and at La Grange, the slopes of the hills, along their lower margin, contain many small nodules of limonite, which render the soils less valuable for brick manufacture. If these nodules be removed by screening, the soils can be used successfully in brick manufacture. But at all these localities there are abundant deposits of clean loess that furnish unlimited opportunities for brickmaking.

The bricks made from the Crowleys Ridge loess usually burn to a good color—cherry-red for hard, and a lighter shade of red for the soft burned ones.

Near Marianna, in the SW. ¼ SW. ¼ sec. 19, T. 2 N., R. 4 E., many acres are covered by a peculiarly colored modification of the loess, which contains a higher percentage of iron oxide than the typical loess. It is a very fine homogeneous deposit and fills the lower portion of all the creeks, ravines, and gullies of the neighborhood. It will prove a superior brick clay and will burn to a rich, uniform red. It is well adapted to the manufacture of ornamental front and pressed brick.

The hilly country north of Poinsett County differs from other parts of the State in the distribution of the loess and its relations to the Tertiary strata. The loess there is found only on the slopes of the hillsides or on the low spurs of the ridge wherever they extend far from its main mass, and it is there a less prominent geologic feature than it is in the country south of Craighead County. In this hilly country its relations to the Tertiary sands and gravels are such that in most localities the loess deposits are more sandy and apparently less homogeneous; the quality of brick that may be made from this soil, while excellent, will not be so fine as that made from unmodified loess.

In Memphis, St. Louis, Des Moines, Council Bluffs, and Ottumwa, Iowa; Omaha, Nebraska City, and David City, Nebr.; St. Joseph, and Kansas City, Mo., and other cities where loess soils are used in brick manufacture, grinding mills are employed to reduce them to the finest powder. In this condition they are fed at once to great dry-pressing machines, from which they are immediately set in kilns. When it is treated thus, or in a similar manner, no material is better suited to brick manufacture. The processes employed in brick manufacture must be varied with the variation in the nature of the brick earth used.

SLOPE SOILS.

At all points along the ridge country, except Helena, the reworked loess is commonly employed in brick manufacture. It occurs on the sides and at the foot of the ridge. The soil is stripped a few inches, to remove the mass of vegetable matter, and the subsoil, to a depth varying from 1 to 5 feet, is used for brickmaking. The clay is thrown into pits, with water, and allowed to stand for two or three days or a week, when it is pugged. It is then molded and dried in the usual manner.

The soils and clays of the slopes present the greatest range of variation in character. They differ greatly within short distances, at places becoming very clayey, at others sandy, or even gravelly. The variation in microscopic appearance is due to the relative erosion, both of amount and rate, to which the various strata have been subjected. In many places, as at Harrisburg, in Poinsett County, and at Wynne, in Cross County, the loess soils have been largely removed by erosion, so that the underlying Tertiary sands have been exposed and the soils of the slope have become more sandy than soils of the same class about Forrest City, Marianna, La Grange, and Helena. The characters exhibited appear to differ locally, also. Where the slope is rather steep the clays and intermingled sands alike are eroded away, having been carried down to the lower lands and redeposited over the flat country as a thin surface soil or sandy loam, but in situations where the slope is less marked the clays alone are carried off, while the sands and gravels are left behind. This appears to be the explanation of the character of the soils along all that portion of the ridge country or slope north of Jonesboro, on the eastern side of the ridge. There the slope of the ridge is gentle and the conditions are favorable for the removal of the clay. But on the west slope of the ridge from Craighead County northward to the Missouri line the slope of the ridge is abrupt, and the erosive agents carry off all that is movable, whether it be sand, gravel, or clay. These are again mixed with much organic matter on the plains below and immediately adjoining the ridge, which modify the soil.

From these slope soils are manufactured most or all of the bricks produced at Paragould, Gainesville, and Jonesboro. Commonly only a few inches of the surface soils are stripped off and used, care being taken not to go too deep into the subsoil, which is too stiff to mold well with the processes employed, and which is, besides, but little different from the ordinary limonitic or hardpan clays of the bottoms. This soil extends out from the ridge toward the east, surmounting the low divides between the numerous drainage areas. The soils higher up in the hills contain more loess clay and less limonite, but commonly more sand.

With such marked differences in the characters of the slope soils or clay at localities very near one another, it is not surprising that the bricks produced exhibit every degree of color, finish, hardness, and durability.

CLAYS AND KAOLINS OF CHEMICAL ORIGIN.

It has been stated that kaolin was derived directly by decomposition of feldspathic rocks. While this is true in a general way, all kaolin is not made in this way. It occurs in small quantities in regions of Paleozoic rocks, where it forms thin bands or fills small pockets. In these places it seems to have been formed by chemical action. It is true that kaolin is practically insoluble, but certain forms of silica are equally insoluble, yet these very forms are soluble under certain conditions if time enough is allowed for solution. The same is doubtless true of kaolin, otherwise we should not have deposits which are far removed from the original feldspathic rocks and which can be explained by no other theory. Either kaolin is soluble in some substance or under certain conditions of which we are as yet ignorant, or it is soluble in the waters that usually traverse the rocks when plenty of time is allowed for reaction to take place.

In any case the kaolin (newtonite) found in small pockets in the rocks of the northern part of the State was not deposited as a sediment as were the shales and sandstones and limestones of that region, nor was it derived by decomposition directly from feldspathic rocks, but it is a secondary deposit, derived by chemical action from the sedimentary beds above and about it.[a] The same is true of rectorite, which occurs in Garland County.

BAUXITE.

The pisolitic clays and kaolins associated with the bauxites of Arkansas, in so far as their origin is understood, do not appear to fall under any of the foregoing classes. Their composition varies from that of an iron ore carrying 55 per cent of metallic iron to that of a true kaolin with but little or no iron. In some places they pass by gradual transition into true bauxite—that is, a hydrated oxide of alumina; in others they are a true kaolin, a hydrous silicate of alumina. In Arkansas, as in southern France and in Ireland, where similar deposits occur, they are associated more or less intimately with eruptive rocks. They occur in pockety deposits of uncertain distribution, with a tendency to form horizontal lenticular beds varying greatly in thickness as well as in character. Their origin is involved in some obscurity.[a]

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[a] See Chapter III of this report, p. 34.

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[a] The most comprehensive report on Arkansas bauxite is that of Dr. C. W. Hayes, published in Twenty-first Ann. Rept. U. S. Geol. Survey, 1899-1900, pt. 3, pp. 441-472. An earlier paper by J. C. Branner (Jour. Geology, vol. 5, 1897, pp. 263-289) contains a brief bibliography of bauxite.

CHAPTER III.

GEOLOGIC AGE AND GEOGRAPHIC DISTRIBUTION OF THE CLAYS.

CONDITIONS GOVERNING DISTRIBUTION.

The distribution of clays depends on the distribution of the geologic formations from which they are derived, and hence on geologic structure. From what has been said of the origin of clays it will be seen that their distribution throughout the State must necessarily depend on the State's geologic history, or the manner and order in which the rocks have been made and unmade. Where we have the crystalline rocks, which yield kaolin on decay, there we may look for kaolins, and in order to look intelligently we must know the distribution of those particular rocks. The clay shales we can expect to find only in association with the Paleozoic rocks, and as they are abundant in the rocks of the Carboniferous system we must ascertain the distribution of the rocks of that age. The Tertiary and Cretaceous clays can be found only with the Tertiary and Cretaceous rocks, and in searching for them it is essential to know the areas of these rocks in the State, the position in which they lie, the character of the various beds, and the places the clays occupy in the series.

These instances are cited for the purpose of showing how indispensable to an intelligent search for clays is a knowledge of geologic structure and the areal distribution of the various geologic formations. A geologic map of the State (Pl. I) is inserted in this report for the purpose of furnishing this information.

PALEOZOIC CLAYS AND SHALES.

The clays of the Paleozoic areas of the State consist of shales of Paleozoic age found in place, and of alluvial or other clays of recent age spread over the lowlands. The clays of the latter class are derived indirectly from the Paleozoic rocks of the surrounding regions and may form brick earths or pottery clays.

When clays are subjected to a great pressure for a long time they become hard and stonelike, forming what are known as shales and slates. Nearly all of the clays of Paleozoic age have been crushed under pressure so great and for so long a time that they have become thus hardened into shales.

The clay shales which were derived from the wear and decay of other rocks were originally deposited in horizontal beds in the water of the ocean or of bays and swamps, and if they are now thrown into folds, raised into mountains thousands of feet above the ocean, and hardened into stone, it is only because they have been crushed till they are hard, pressed laterally into folds, and elevated until they stand high above their original positions. Subaerial erosion has subsequently removed much accompanying and surrounding material, and in places these shales have weathered into residuary clays, such as have been described on page 20.

The clays of the Paleozoic regions have values peculiarly tneir own, for while the clays of the Tertiary area of the State are especially well adapted to the manufacture of pottery, those of the Paleozoic regions are largely adapted to the production of fire bricks, sewer pipes, and paving bricks.

The Paleozoic rocks have furnished the greater part of the refractory material of the world. These clay and clay shales do not as a rule possess as high refractory properties as bauxite, steatite, graphite, or magnesite, but the latter are much less abundant and are for this reason much more expensive, while articles made from clays and shales are sufficiently refractory for most of the common uses for which refractory materials are employed, and the abundance and cheapness of such clays insure for them a constant and ever-increasing demand. In the United States the clays and clay shales of the Carboniferous rocks are extensively used for certain manufacturing purposes, while raw clays are shipped to points all over the country to be used for the manufacture of retorts and furnace linings of special forms.

The various zinc-smelting works in the United States make their own retorts, and the clays used for this purpose are brought to the reduction works from well-known Paleozoic beds. And it should not be forgotten in this discussion of the character and distribution and uses of the clays of this class that their value, other things being equal, is determined by their proximity to manufacturing centers and to competing lines of railway transportation. These important factors have built up the fire-clay industries of St. Louis and Cheltenham.

The St. Louis, Iron Mountain and Southern Railway extends along the eastern edge of the Paleozoic area of Arkansas north of Arkadelphia. The southern border of the Paleozoic runs nearly due west from a point on Ouachita River a few miles north of Arkadelphia.

Within this Paleozoic area the clays and clay shales are unevenly distributed. In the Ordovician region, lying north of the Boston Mountains, shales and clays of value are much less abundant than they are in the Boston Mountains and in the Carboniferous rocks farther south. Again, in the Silurian region of the great Ouachita anticline, running from near Little Rock to the Indian Territory line, in Polk County, there are many mountains of novaculite in which there are but few valuable beds of shale. In the great river bottoms of the Arkansas there are large tracts covered by river silts that are not available for the manufacture even of the most ordinary building bricks. However, there is not a single county in the entire Paleozoic area in which fairly good brick clays may not be found.

CRETACEOUS AND TERTIARY CLAYS.

It is only for the sake of convenience in presentation that the Cretaceous and Tertiary clays of the State are here treated in the same chapter. A glance at the geologic map of Arkansas accompanying this report (Pl. I) shows that rocks of Cretaceous age outcrop over a relatively small part of the State.[a] They are found in only about seven counties.

During Tertiary time, a period not far removed from the present, geologically, a large part of the State of Arkansas was covered by the ocean. The western shore of the Tertiary sea entered the State on the southwest somewhere in the vicinity of Ultima Thule, and passed into Missouri near the line between Clay and Fulton counties. The western margin of the Tertiary, as shown on the geologic map (Pl. I), marks approximately the old shore line. With the northern limits of this sea we are not now concerned, but on the east it extended nearly to Tennessee River, covering all of eastern Arkansas, while almost all the State of Mississippi lay beneath its waters.

All waters that flowed into this Tertiary sea carried down great quantities of sands and clays, just as to-day sands and clays are being carried out into the Gulf of Mexico by the Mississippi and by all the surface waters that flow into it. This material was spread out over the floor of the sea in beds as nearly horizontal as the nature of the bottom and the currents would permit, and with them were mingled the shells and bones of animals that lived and died in the water and the leaves and stems of plants that were floated out by the streams. Later the land was elevated until the silt of that ancient sea bottom now stands 375 feet (at Little Rock) above the present ocean's level.

During this depression of the land the Tertiary clay beds of the State were deposited, and the conditions under which these beds were formed satisfactorily account for their characters, their distribution, and their included fossils.

Should we go back a little further in geologic time we should be able to account also for the clay beds of the Cretaceous region in the southwestern corner of the State. The conditions under which they were laid down differed but little from those under which the Tertiary clays were formed. Neither the Cretaceous nor the Tertiary clays are hard, but neither are they geologically very old, nor have they been subjected to that great pressure that has so often affected the older clay beds of the earth's crust, many of which now form shales and slates.

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[a] [illegible] Ann. Rept. Geol. Survey [illegible]

The Tertiary geology of Arkansas south of Arkansas River has been described in detail by Prof. Gilbert D. Harris,[a] and the Tertiary and later beds of the Crowleys Ridge region of northeastern Arkansas by Dr. R. E. Call.[b] The present report does not undertake to deal with questions of stratigraphy within the Cretaceous, Tertiary, and Quaternary areas, except in so far as they relate to the details of the clay deposits.

The general geology of the Cretaceous and Tertiary portions of the State should be fairly well understood by those who have to deal with the clays that occur in those formations. The Cretaceous beds are older than those of Tertiary age, which they underlie. They are exposed in the counties west of Arkadelphia, namely, in Clark, Nevada, Pike, Hempstead, Howard, Sevier, and Little River. Everywhere in this region they slope gently toward the southeast.

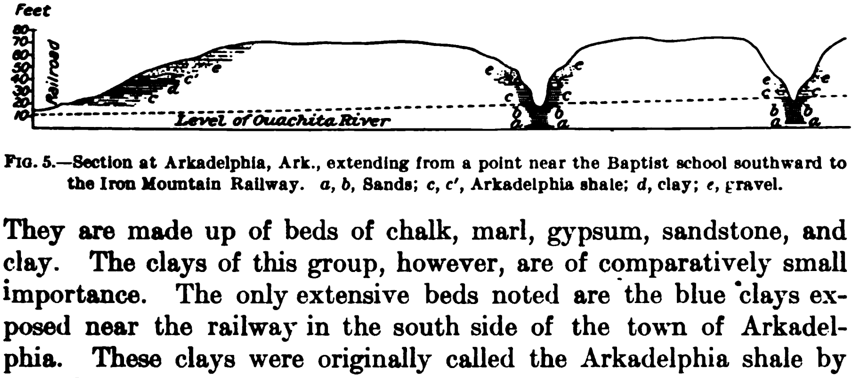

FIG. 5.—Section at Arkadelphia, Ark., extending from a point near the Baptist school southward to the Iron Mountain Railway. *a*, *b*, Sands; *c*, *c′*, Arkadelphia shale; *d*, clay; *e*, gravel.

They are made up of beds of chalk, marl, gypsum, sandstone, and clay. The clays of this group, however, are of comparatively small importance. The only extensive beds noted are the blue clays exposed near the railway in the south side of the town of Arkadelphia. These clays were originally called the Arkadelphia shale by Prof. R. T. Hill and were believed by him to belong to the Tertiary.[c] Later, however, Prof. G. D. Harris found that they belong to the Cretaceous.[d]

It is not known that the Arkadelphia shale has any economic value. It is usually so interbedded with thin laminæ of sand that it can not be used for the manufacture of pottery, but probably this same bed may elsewhere be suitable for the manufacture of pottery or available as fuller's earth. This shale bed is exposed at several places about the town of Arkadelphia and also on the upper part of Big Deciper Bluff 5 miles southwest of the town. The yellow sandy clay overlying the chalky marl on the Wright place, on Little

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[a] Ann. Rept. Geol. Survey Arkansas for 1892, vol. 2.

[b] Ann. Rept. Geol. Survey Arkansas for 1889, vol. 2.

[c] Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2.

[d] Ann. Rept. Geol. Survey Arkansas for 1892, vol. 2, pp. 15–19.

Deciper Creek, seems to be the same shale bed. Professor Harris has identified the Arkadelphia blue shale again on Mine Creek, near the old town of Nashville, where it is 4 feet thick.[a]

Within the Cretaceous area there are large areas covered with buckshot clays. These clays are not of Cretaceous age, but are much newer—Pleistocene and Recent—and are made of the residue of any clay-bearing strata that may be at hand after the decomposition of the underlying rocks. In the low, flat lands, commonly known as "slashes," thin beds of plastic clays are found at places where acidulated waters have leached the iron from the soil. Some small potteries get their clays from such places. The supply of available clays of this kind is uncertain, and most of the areas covered by them are small. Such clays occur in the flat lands of the Cretaceous, Tertiary, and Quaternary areas of the State, which, however, are not alluvial lands, properly speaking.

Reference has been made to the waterworn materials that occur in the Tertiary region of southern Arkansas. This material is at some places extremely coarse, made up of cobbles the size of a man's head or even larger, and at others consists of pebbles no larger than a hickory nut. This gravel spreads over and obscures the outcrops of the Tertiary beds throughout the region, and is especially thick along the foothills on the northwestern margin of the Tertiary exposures. In thickness the deposit varies greatly, being in one place only a few inches and in another from 25 to 40 feet thick. In some places it has a tendency to accumulate in depressions; in others it is found in considerable quantity only on the hilltops. Inasmuch as the presence of this waterworn material often interferes not a little with prospecting for pottery clays these peculiarities of its distribution should be kept in mind by prospectors and clay miners.

The presence in the pottery clays of leaf impressions has been mentioned. A small collection of these was made and sent to Lester F. Ward, of the United States Geological Survey, for the purpose of ascertaining whether they threw any light upon the geologic age of these clays. Professor Ward's conclusions on this subject are that the beds are probably lower Tertiary, but he says that the specimens from the Henderson clay pit, north of Benton, Saline County "have a very curious and suggestive resemblance to some of the Amboy clay leaves, and I strongly suspect that you have gotten into the Cretaceous."

It is interesting to know that the fossil leaf impressions from these clays are probably all of new species, but the fact that they are new, as Professor Ward remarks, decreases their diagnostic value in determining the age of the deposits. The age of the pottery clays could not therefore, without more collecting at least, be decided by the fossil plants peculiar to the beds themselves. Marine fossils of Eocene age have been found east of the outcrops of the clays, however, at Warren, in Bradley County; at Monticello, in Drew County; at Rison, Kingsland, and about New Edinburgh, in Cleveland County; and at White and Red Bluffs, on Arkansas River, in Jefferson County. The pottery clay beds of Saline and Hot Spring counties seem to dip beneath the fossil-bearing beds mentioned above, and must therefore be not later than Eocene. For these reasons these beds are spoken of in this respect as being of Tertiary age.

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[a] Ann. Rep. Geol. Survey Arkansas [illegible], vol. 2, pp. [illegible]

With this understanding of the general characters, age, and origin of the common Tertiary pottery clays of the State we may take up the details of their occurrence.

The Tertiary clays are the most important in the State of Arkansas. As already stated, they, with their accompanying sands, marls, and organic deposits, underlie a large part of the State east and south of the St. Louis, Iron Mountain and Southern Railway south of Arkansas River. North of this and east of the Paleozoic hills the sediments are chiefly Quaternary deposits, except Crowleys Ridge, the lowest part of which is Tertiary. Most of the beds of this series were laid down in the sea when it extended over all of southern and eastern Arkansas and as far north as the mouth of Ohio River. The sediments that were washed into this Tertiary sea sloped gently toward the middle of the gulf, and the hardened beds they formed, now lifted above sea level, still retain that slope. During Tertiary time the land must have risen from beneath the water more than once, for we have at many places beds of lignite that could be formed only as swamp deposits. After the lignites had been formed the land was again depressed and covered by the sea and the accumulation of sediments continued. Everywhere over the area those sediments were laid down in beds that were approximately horizontal but dipped gently seaward. After the final elevation of these beds above the sea, the streams carved out our present topography in the uppermost of the Tertiary beds.

From this brief sketch it will be seen that the sediments laid down during Tertiary time vary from place to place in thickness and in character, just as any marine sediments of the present time vary. Some of the beds are clays and some of them are sands and gravels. The fresh-water or land deposits also vary, just as such deposits vary at the present time.

The fire clays of the Crowleys Ridge region are everywhere associated with beds of Tertiary lignites, which outcrop in the basins of several of the larger streams. Lignites and fire clays occur in the NE. ¼ NE. ¼ sec. 26, T. 4 N., R. 4 E.; NW. ¼ SW. ¼ sec. 8, T.

11 N., R. 4 E.; NE. ¼ NE. ¼ sec. 20, T. 10 N., R. 4 E.; sec. 30, T. 16 N., R. 5 E.; and in sec. 36, T. 19 N., R. 6 E.

At each of these localities the fire clays underlie the lignite beds, and from this relation it is fair to infer that similar clays occur under all the lignite beds in this area. No attempts have been made to use these clays for making fire bricks or tiles.

In the first-named section, which is in St. Francis County near the Lee County line, on the east side of Crowleys Ridge, the exposure is well up in the hillside, facing a small ravine tributary to St. Francis River. The clay is from 3 to 4 feet thick, but is difficult of access and extensive stripping will be required to mine it, or if a drift be made into the hillside it will require timbering. This clay is light drab in color when wet, but it dries to white or nearly white.

The association of lignite and fire clays serves to explain the light color of the clays. Around all the lignite deposits in the Crowleys Ridge region there are extensive beds of blue or black clays, containing selenite crystals, which pass into these light-colored clays by hardly perceptible gradations. Some masses of lignite detached from great beds near at hand are imbedded in the horizontally stratified blue clays that overlie the lignite beds. The clays in contact with these masses are lighter colored, some of them almost white, having apparently been bleached by the action of the organic matter of the lignite. The lighter color of the underlying fire clays is due to the same processes. Organic matter that finds access to clays and soils acts as a powerful discoloring agent; from black or blue or even red they may be changed to drab or white. This phenomenon is well illustrated along Copperas Creek in Cross County, near La Vasque, at the base of the great section there exposed, and also along the base of the Cherry Valley section, where the organic matter is in the form of leaves and other vegetable detritus. In Greene County in sec. 33, T. 19 N., R. 5 E., and along the clay bottoms of [illegible] Creek, at the point where the lignite forms the base of the hill in sec. 8, T. 11 N., R. 4 E., similar phenomena are to be seen.

At the Cherry Valley locality the lignite outcrops on the surface of the ground and not far away from it is an outcrop of the underlying fire clay. This clay forms the bed of [illegible] Creek for a distance of [illegible] or more, passing under it and into the high bluffs [illegible]. A [illegible] under the bed of lignite [illegible] Creek a half mile or more to [illegible] passes northward [illegible] beneath it. [illegible] thin bed higher up in the hillside [illegible] derived from the adjacent hills.

At the point of the section where the lignite is exposed in its greatest thickness 3 or more feet of this clay appear in the hillside facing the stream. It is chocolate brown when wet, its color being due to the presence of minute particles of finely divided lignite, for there is no other coloring matter present.

The third locality is on a small stream known as Otter Creek, 1½ miles northwest of Bay Village. The drab fire clay is about 2 feet thick on the immediate bank of the stream. The clay extends over much of the surrounding region and is of comparatively easy access. It has been put to no use thus far.

The fourth locality is in Greene County, on the banks of Beech Creek, where the fire clays are indurated into a soft light-drab shale with conchoidal fracture. It passes under a cultivated field near the stream to the west and disappears in the high hills that border the creek on the east.

Above the clays in this Beech Creek section lie indurated and quartzitic Tertiary sandstones. If these deposits are ever deemed of sufficient importance to work, they can be ground so that they may be used. The outcrop extends for a long distance up the stream, and there is no doubt that these clays underlie all the country immediately adjoining.

Another locality in Greene County where fire clays occur is southwest of the place last mentioned, in sec. 10, T. 17 N., R. 4 E. An analysis of this clay was made at the St. Louis Sampling and Testing Works and is reported as follows:

Analysis of clay from Greene County.

Moisture	17.64
Combined water and organic matter	6.63
Silica (SiO_2)	70.43
Alumina (Al_2O_3)	19.15
Lime (CaO)	.52
Magnesia (MgO)	Trace.
Iron	1.70
Alkalies	1.84
	100.27

The clay at this place outcrops on the side of a hill, in a ravine near its base, and may be connected directly with that found at the Lovelady place, in sec. 30, T. 18 N., R. 5 E. It could be employed in the manufacture of fire bricks of ordinary grades, as well as for sewer pipes, tile work, and similar uses.

In sec. 30, T. 19 N., R. 6 E., there is a deposit of fire clay in the bank of a small stream. Probably the same bed is reached in a well in the Cache bottoms, 1½ miles farther southwest. These beds appear to be related to those on Beech Creek near Lovelady. They are of drab color and are exposed in the stream to a thickness of 5 feet or more.

No pottery clays are known in the Crowleys Ridge region. It is probable, however, that local deposits may be found in some of the low grounds of the slashes of the region.

Throughout the Crowleys Ridge country, wherever erosion has gone deep enough to reach the cross-bedded Tertiary sands, it has exposed numerous thin undulating strata of bright-red, pink, purple, gray, white, or yellow ochers. In certain localities, as in the Prussian Jewish Cemetery at Helena; at Double Head Bluff, in St. Francis County; at Wittsburg, on Wolf Creek, in Poinsett County; at Gainesville, in Greene County, and at Chalk Bluffs, in Clay County, these clays are found in abundance. Commonly, however, they are much intermixed with sands and are very patchy in their occurrence.

The only uses to which they are known to have been put are for painting outbuildings and fences and in dyeing cloth. Since they are so local in occurrence and are commonly found in small quantities they are not believed to possess any economic value.

Analysis of pink clay from Gainesville, Greene County.

[Specimen dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO$_2$)	71.17
Alumina (Al$_2$O$_3$)	18.44
Ferric oxide (Fe$_2$O$_3$)	2.77
Lime (CaO)	.25
Magnesia (MgO)	.44
Alkalies, by difference	.90
Loss on ignition	6.03
	100.00
[illegible] sand in washed clay	14.52

In the roadway on the west edge of the village of Gainesville several feet of this clay outcrops in pockets. There is no continuous deposit of it in the immediate vicinity of the village, though one occurs in deep washes near the roadway in sec. 32, T. 18 N., R. 5 E. In this locality the pink pipe clay occurs in beds that range in thickness from [illegible] to [illegible] inches and are separated by cross-bedded white sands.

At Wittsburg there is another deposit of pipe clay which is characteristically patchy and wanting in continuity. In the west edge of the village, in a gully crossed by the roadway leading to Wynne, there are beds of pipe clay that are in places as much as 3 feet thick. In color they range from white to deep red through drab, yellow, and pink. A sample of the red and pink clay of this locality was analyzed with the following results:

Analysis of pink clay from Wittsburg.

[Specimen dried at 110°-115° C. R. N. Brackett, analyst.]

Silica (SiO_2)	69.55
Alumina (Al_2O_3)	15.20
Iron oxide (Fe_2O_3)	8.10
Lime (CaO)	.58
Magnesia (MgO)	.97
Potash (K_2O)	.52
Soda (Na_2O)	.50
Phosphoric acid (P_2O_5)	.20
Loss on ignition	5.72
	101.34
Water at 110°-115° C	2.24
Air-dried fine white sand	25.48

QUATERNARY CLAYS.

The Quaternary deposits of Arkansas occupy a large area east and south of the Paleozoic group. South of Arkansas River these deposits, except along the larger streams, are comparatively thin, and between them lie many outcrops of the underlying Tertiary and Cretaceous sediments. North of Arkansas River the Quaternary deposits are much thicker. In all the flat country of northeastern Arkansas Quaternary deposits completely cover all the older formations. Tertiary rocks outcrop along the base and sides of Crowleys Ridge.

Crowleys Ridge enters the State in Clay County and runs due south to Helena, in Phillips County. The country traversed by this ridge is low and, from a geologic point of view, somewhat monotonous. Its geology as related to the clays and clay industries can be presented most conveniently by a brief statement of the geologic features of Crowleys Ridge itself.

The Quaternary clays of the Crowleys Ridge region are either (1) loess or ridge clays, or (2) ridge-land clays, found west of Crowleys Ridge.

The first of these soil and clay groups is found mainly on the higher portions of Crowleys Ridge. The second occurs only on the more elevated portions of the low country, but its chemistry and distribution present certain peculiar and interesting facts that call for its separation from the soils of the lowlands proper.

From Helena nearly to Jonesboro the loess is the characteristic soil of the higher portions of Crowleys Ridge. At some places where ravines are eroded along the eastern margin of the ridge, at right angles to its trend, this material forms precipitous walls, the bottoms of which rest on gravels and sands. In other localities loess soils overspread the slopes of the hills to varying depths. These redeposited loess soils are not so homogeneous as the undisturbed portions of the loess, for they contain more or less gravel and sand, derived from the neighboring hills.

The limonitic buckshot lands, as has already been stated, are widely distributed, for, owing to the method of their formation, they are liable to be made wherever the conditions indicated exist. Therefore the buckshot are not confined to clays of any particular age. The conditions most favorable for their formation, however, as might be expected, have existed and still exist in the widespread flat Tertiary and post-Tertiary portions of the State, and in the hardpan of the prairie region.

The region between Crowleys Ridge and White River is diversified with prairie and wooded lowlands and traversed by low ridges which have a general north-south trend parallel to the drainage lines. Though they stand only from 5 to 15 feet above the general level, they nevertheless constitute a remarkable topographic feature. On these ridges several towns and villages are located—Surrounded Hill, Brinkley, Wheatley, and Palestine, for example.

The geology of these low divides is not positively made out. The soils which usually cap them are entirely different from those which form the surface of the distinctively prairie region. It is commonly a yellowish-brown loam resembling the loess soils of Crowleys Ridge, but it is not an alluvium. Beneath it are the buckshot clays, as is shown in well sections. Extensive deposits of this loam occur in portions of secs. 10, 11, 14, 15, and 22, T. 3 N., R. 2 W. The ridge extends away toward Clarendon, but disappears in the pine flats a few miles south.

The buckshot clays cover nearly all the country contiguous to and west of Crowleys Ridge. They also form a narrow belt along the eastern edge of the ridge south of Poinsett County; but this eastern belt entirely disappears at places in the southern portion of the ridge. These clays have been noted at but few places in the country east of St. Francis River, where the lands are composed mainly of alluvium, and are in great part subject to periodic overflows. In the region west of the ridge these clays constitute all the second bottoms along L'Anguille, Cache, and White rivers, and at many places along those streams they appear from beneath the alluvium. This statement holds also for the White River region south of the Bald Knob and Memphis branch of the Iron Mountain and Southern Railway. The entire prairie region of St. Francis, Cross, and Poinsett counties is underlain by this soil. Farther west, in Woodruff, Monroe, Prairie, and Lonoke counties, it is commonly observed either in the washes on the prairies or in the "post-oak slashes" of that region, and is penetrated in all well sections. All the post-oak regions of the Crowleys Ridge area are characterized by soil of this sort. In some localities, as at Forrest City, Marianna, Jonesboro, and Paragould, it ascends the slopes of the hills a number of feet (at some places as much as 40 feet) above the general level of the surrounding region. It occurs also in occasional small basins at the very top of the ridge, but is there mixed with loess and is not so sandy as it is in the lowlands. In many localities in the Cache and L'Anguille bottoms it rises to the surface and forms the soil over extensive areas.

The buckshot clay is commonly a light-gray sandy clay, nearly impervious to water, containing an abundance of small nodules of limonite. There are usually several thousand of these little nodules to the cubic foot of earth. At many localities the clay is removed from the soil, or it never was present, so that the soil now consists of only the coarser sands and the limonite. These nodules lie in countless thousands on the surface, giving a characteristic lumpy surface to the soil, which, where they so occur, is too poor to support even a scanty vegetation. Along the borders of some streams and ravines the nodules have weathered out to form layers a foot or more in thickness, notably at the mouth of England Creek (in the NE. ¼ SW. ¼ sec. 19, T. 10 N., R. 4 E.) and in the valley of Big Creek about Jonesboro.

In general, then, it may be said this limonitic hardpan, or buckshot, is found over all the low country for 50 miles or more west of Crowleys Ridge. On the east of the ridge it is but a narrow fringe along its base below Poinsett County, but north of this county it spreads over the whole region as a subsoil, in places rising to the surface and varying in depth from 3 to 7 feet. It extends eastward to the alluvial bottoms of the St. Francis. Along Cache River in Greene and Clay counties much of the land is made up of these slashes or buckshot soil.

This buckshot soil is used at Jonesboro, Gainesville, Paragould, and Rector for the manufacture of bricks, but it is ill suited for this purpose. The limonite is reduced to metallic iron in the parts of the kiln next to or near the fire, and this gives the bricks a black, spotted appearance, which contrasts unpleasantly with the color of the body of the brick. In the yards employing this brick earth the processes of molding are crude and none of the higher grades of machinery are in use; all the bricks are hand molded and none are re-pressed.

REMARKS ON THE ANALYSES.

Comparison of the analyses given in the table on pages 236–237 will help to an understanding of the colors of the bricks made in the region. Clay for making bricks of good red color should contain iron; clay for brown bricks should contain manganese. The brick earths from Paragould and Jonesboro and one sample from Harrisburg contain most manganese; the others contain but a trace or none of it. The rich colors of the Jonesboro-Paragould bricks therefore seem to be due to these two substances. Clays that are deficient in both these substances, or that contain one of them in lumps—as the soil from the buckshot land at Harrisburg—will make bricks of poor color, which, however, may be modified or improved by the addition of soils containing iron or manganese.

The colors of bricks depend also on the degree of heat to which the kilns are raised and the chemical combination of the iron or manganese. Careful manufacturers of bricks keep close watch on these important factors and produce bricks of uniform color and hardness. In the Crowleys Ridge region the refinements of brick manufacture have not been attempted, although the loess soils found there are preeminently suited to the production of fine brick.

CHAPTER IV.

REPORT BY COUNTIES.

ARKANSAS COUNTY.

The southern portion of Arkansas County lies in the flat bottom lands of White and Arkansas rivers. The central and northern parts are higher. All the large streams of the county flow south. Between the streams are gently rolling prairies, which vary in width from 2 to 15 miles. The Stuttgart and Arkansas River Railroad follows the main ridge or prairie land from Stuttgart to Gillett. The ridge ends about 5 miles south of Gillett.

The prairie or ridge land in the northern part of the county extends eastward to White River. From near Searcy to Crocketts Bluff, in Arkansas County, a series of bluffs or steep banks extend along the west side of White River. The character of the country along the river is made apparent by such names as Devall Bluff, Mount Adams, and Crocketts Bluff. South of Crocketts Bluff the high bank on the west side of White River gradually falls away into low bottom lands.

The soils of the county fall naturally into two groups—(1) the alluvial sandy soils along the rivers and large streams and (2) the prairie soils. The soils of the prairie lands are reddish to gray clay, which has a maximum thickness of 30 feet. Below the surface clay comes a bed of quicksand, or common fine sand, which furnishes the water supply for the shallow wells of the district.

The following well record at Stuttgart gives the characteristic strata of the prairie lands:

Section of strata at Stuttgart.

	Feet.
Drab-colored clay	1- 1½
Red to brownish clay	8-10
Reddish sand	3-15
Red or blue clay, locally called soapstone	8-15
Gray quicksand	3-30
Gravel, water bearing	3-12
Quicksand	(?)
Clay	(?)

A bed of lignite is found at many places just above the bed of gravel.

The only clay product manufactured in the county is common building brick, made from the surface red clay at Stuttgart.

ASHLEY COUNTY.

The rocks all through the higher parts of the county belong to the Eocene (Tertiary). The lowlands along Saline River, on the west and east of Overflow Creek, and along Bayou Bartholomew are mostly alluvial lands, where only brick clays may be looked for; or they are "slashes," where occasional pockets or thin beds of common pottery clays may be found.

The beds of the higher portions of the county are nearly horizontal and consist, for the most part, of sands and clays in various combinations and occasional beds of lignite.

The well sunk at the court-house at Hamburg is said to have passed through the following section:

Section in well at Hamburg.

	Feet.
Sandy soil	3–4
Not recorded	23
White pipe clay	10
Red clay	3–6
White quartz sand	20
Pebble bed.	

The pipe clay of this well section suggests that valuable clays may be found at some places in Ashley County, probably on slopes where the streams have cut deep into the soil. They will probably be found also in the deep wells.

G. D. Harris, while working on the geology of Ashley County, was informed that in the wells "a blue or light-gray clay occurs to a depth of 10 feet. This clay contains some leaf impressions." The character of plant-bearing clays found in other counties in Arkansas suggests that the clays may be available for making pottery and for other purposes.

The only clay-working industry in Ashley County is a common brick plant run by Nolly Brothers at Hamburg.

BRADLEY COUNTY.

The northern and western part of Bradley County is a rolling country which slopes gradually toward the bottom lands of Ouachita River. On the east the lands drop away rather abruptly toward Saline River. Along the larger streams—the Ouachita, the Moro, and the Saline—the soils are mostly alluvial, and the original Tertiary sedimentary beds are exposed at only a few places. G. D. Harris states that "the undisturbed Tertiary deposits of Bradley County consist of light colored lignitic clays, usually intermixed with more or less light colored siliceous sand. Bluish or black clay is occasionally met with in digging or boring wells, and there is some pure lignite."[a]

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[a] Tertiary geology of southern Arkansas: Ann. Rept. Geol. Survey Arkansas for 1892, vol. 2, p. 119.

He found gray clays exposed on the road running north from Johnsville toward Warren and 4 or 5 miles from the former town. He gives the following record of the well of Lee Hammaker, in sec. 8, T. 12 S., R. 6 W.:

Record of well of Lee Hammaker.

	Feet.
Light, even-bedded clay.	28
Clay ironstone	2
Reddish-white and yellow clay	5
Blue fossiliferous clay	6
Clay ironstone	1
Black sand with water	5

At Alga Bluff, on Saline River, in sec. 21, T. 13 S., R. 9 W., a section about 75 feet thick is exposed. The lower half of this section contains two thin beds of lignite and two beds of clay—one 3 feet thick, between the beds of lignite, the other 16 feet thick, overlying the upper bed of lignite. These clays have not been examined chemically, but they are worthy of examination and practical tests.

At Crawfords Bluff, on Saline River, beds of lignitic clay are exposed again. In the region between Johnsville and Long View, wherever the drainage has cut deep channels, these lignitic potter's clays are to be looked for beneath the heavy gravels.

About one-half mile west of the point where the railway from Monticello to Warren crosses Saline River the railway cuts a terrace-like ridge. The upper 4 feet exposed in this cut is a bright-red soil, and the underlying bed is purple clay.

About Warren the surface loam is in many places adapted to brickmaking, but so far as could be learned no clays of importance beyond the brick earths have been found in the immediate neighborhood. The Tertiary (Eocene) fossiliferous beds are exposed in the railway cut in the town. Over all of Bradley County the Tertiary (Eocene) beds are either exposed at the surface or are concealed by their own weathered remains or by a thin sheet of Pleistocene gravel and sand. Most of the weathered Tertiary clays of this county form excellent brick clays.

In sec. 20, T. 14 S., R. 9 W., a well dug beside the road leading from Warren to Johnsville has the following section:

Section in well in sec. 20, T. 14 S., R. 9 W.

	Feet.
Sandy loam	2
Red sandstone with pebbles	8
White pipe clay	4
Sand.	

It may reasonably be expected that valuable clays will be found in connection with the lignites known to exist at various places in

Bradley County. One of these exposures of lignite was visited at Goulets Island, on Saline River, in sec. 24, T. 17 S., R. 10 W. The following section is exposed on the left bank of the stream at that place:

Section at Goulets Island, Saline River.

	Feet.
Sand and clay	6
Clean sand	10
Pebbles and sand	10
Lignite	2
Blue-gray sand and clay	2

The only clay in this section underlies the lignite, and is too far below the surface and contains too much sand to be of any practical value. The lignite is too thin to be worked and has no value

Several years ago the statement was published that "Thirty-six varieties of commercial clays and shales * * * have been found * * * within a radius of 3 miles from the town [of Warren], of which twenty consist of material used in the manufacture of vitrified pipe and paving brick, and the remainder * * * material used in the manufacture of terra cotta, drain tile, earthenware, and pressed brick."[a] Such a statement must be accepted with allowances. As pointed out elsewhere in this report, whether a clay is available for a given purpose can generally be determined only by practical tests. It should not be forgotten also that a clay, in order to be commercially useful, must be abundant, accessible, and cheap. In spite of the fact that the clays of Bradley County have not been tested as they deserve to be, the geology of the county leads to the reasonable belief that it contains large bodies of valuable clays. Only one establishment in Bradley County is engaged in the manufacture of clay products. This is a plant for making common soft-mud brick, located at Warren, and operated by Moore & Gannway.

CALHOUN COUNTY.

GENERAL GEOLOGY.

The geology of Calhoun County can best be understood by a study of the bluffs exposed along the right bank of Ouachita River in Union and Ouachita counties. These bluffs are made up of a series of clays, sands, and lignites which rise to a height of 200 or more feet above the ordinary stage of the water in the river. These soft beds now end abruptly at the river or at the margin of its immediate valley, but originally they extended across what is now the flood plain of the Ouachita and covered Calhoun County, as they still do, though in a modified way.

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[a] De Malher, M. L., Arkansas Gazette, January 20, 1884, p. 5.

The section observed on the right bank of the Ouachita at Wilmington Landing gives a better idea of the geology of Calhoun County than any single exposure known in the county itself. That section is therefore repeated at this place.

Section at Wilmington Landing.

	Feet.
Sand on the hilltop	2
Sandy clay	5
Light-gray clay	2
Pinkish clay	3
Fat buff clay with sandy patches and lignite	16
Tough, sandy light-colored clay	7
White sand	3
Brown coal or lignite	3
Fat dove-colored clay	3
Sand with clay laminæ	5
Pink sandy clays and sands	10
Concealed	10
Level of Ouachita River	90

In dealing with the geology of Calhoun County we should remember that the beds exposed in the section at Wilmington Landing formerly covered the region to the east and north, and that water has gradually cut away the beds and lowered the whole land surface to its present level.

Beyond the river at Wilmington and farther north, toward Summerville, for several miles, the country is very nearly flat and but little elevated above the flood plains of the river. There is, however, an almost imperceptible rise as one approaches Hampton, and a short distance north of Hampton the country is at or about the same elevation as the elevated country at Wilmington Landing.

Over the lower country in the southern part of the county, and indeed almost everywhere east of the Ouachita, the lands are made up of river silts and alluvial and buckshot clays, so common in the slashes and boggy "crawfish lands." This surface covering is of later date than the underlying stratified beds, which are everywhere obscured. The Recent materials cover the older sediments throughout the county by spreading out over the flood plains of all streams.

On the higher lands of Calhoun County there is a widespread overwash of waterworn pebbles. Most of these pebbles are of novaculite, but many quartz pebbles are mingled with them. The novaculite that makes up the great bulk of the gravels is so restricted in its distribution that there can be no question about the origin of these pebbles. The novaculite rocks extend from a point near Little Rock on the east to Hot Springs and Dallas, in Polk County. Almost everywhere they form mountains, generally very steep and rugged. It is from these mountains of novaculite that the novaculite pebbles have been spread out like a great blanket over all the counties of the State lying south of the Ouachitas or novaculite ridges of Pulaski, Saline, Hot Springs, Montgomery, Pike, and Polk counties. The quartz of the pebble beds is doubtless derived from the same region, for the novaculite shales are noted for the great number of thin quartz veins they contain. The fact that the pebbles generally underlie the silts and alluvial beds of the flood plains of the streams shows, too, that they are older than these silts. They seem to have been brought to their present position at the time when the Tertiary land was emerging from the bed of the sea, having been spread out by the undertow of the retiring waters.

These gravels are most abundant on the tops of the highest hills of the region, where they make excellent roads, or beneath the soils along streams. This is because they were originally spread over an approximately flat region; subsequent erosion has removed some of this material, thus making valleys in which the gravels are concentrated beneath the silts and soils that have later accumulated above them.

CLAY DEPOSITS.

Beneath the gravels and immediate surface soils lie the soft Tertiary beds referred to as cropping out in the bluffs of the Ouachita. These deposits contain many beds of pottery clay. Only a few of the outcrops of these beds can be noted here, but anyone who will bear in mind the general geologic structure of the region, as stated above and as shown in the section on page 17, can readily trace the beds and will know where to look for these clays when they have been found at a single locality.

About 3½ miles north of Hampton, at a point where the Hampton-Chambersville road crosses Rocky Branch, on the slope of a hill about 150 feet south of the stream, is a bed of greenish-gray potter's clay. It is not well exposed and neither its upper nor its lower limit could be seen when the place was examined, but it appears to have a thickness of about 4 feet. It can not be stated positively that the clay exposed is in place, but if it is the bed will be found to continue both up and down Rocky Branch at the same elevation, and it is quite probable that it may be found also on the north side of this stream at about the same elevation.

About 3 miles south of Chambersville, just south of Whitewater Creek, at a place where the Hampton-Chambersville road ascends about 40 feet from the bottoms to the higher land, probably in the SW. ¼ sec. 3, T. 12 S., R. 13 W., potter's clay is exposed in the face of the hill in the road. The thickness of these beds can not be determined without digging, but they seem to be from 10 to 20 feet thick at the place mentioned, and are well above all possible overflow of the neighboring streams. The outcrop extends around the face of the hill to the northeast and southwest from the road, while the beds penetrate the hill to the south. In all probability the outcrop will also be found following the face of the hills that skirt the valley of Whitewater Creek along its right bank.

In the Chambersville-Hampton road, a little more than a mile south of the outcrop last mentioned, similar potter's clay is exposed in a gully on the north side of the road.

About 2 miles south of the point where the same road crosses Whitewater Creek potter's clays are exposed again by the roadside in the brow of a low hill facing northwest. This place is probably in the SW. ¼ sec. 15, T. 12 S., R. 13 W., about a quarter of a mile southeast of Dawson's schoolhouse. The following is the section exposed:

Section in SW. ¼ sec. 15, T. 12 S., R. 13 W.

	Feet.
Soil with pebbles and silicified wood.	
Greenish lead-colored clay	5
Brown coal	2
Clayey sands (base concealed)	4

Some of the cobbles in the soil overlying this section are 6 inches in diameter. With the exception of the fossil wood and a little quartz they are all of novaculite.

The outcrops of clay and brown coal extend both to the north and south of the road.

A little more than a mile south of Chambersville, probably in the SW. ¼ sec. 27, T. 11 S., R. 13 W., on Henry Clay's place, a bed of potter's clay 4 or 5 feet thick is exposed beside the road. It contains a few leaf impressions, and in general appearance closely resembles the clays used at Perla. This clay bed will be found to continue to the east of the Chambersville-Hampton road into the woods, while to the west it skirts the low hill north and west of Henry Clay's farmhouse.

Mr. Siebenthal reports a bed of gray plastic clay, from 6 to 10 feet thick, on the railway at a place where it crosses from Cleveland County into Calhoun County, in sec. 4, T. 11 S., R. 13 W., and the same bed again about 500 paces west of the first-mentioned exposure. Good pottery clay is reported on the Jordan place, in sec. 6 of this same township, and also on the Lightfoot place, 1 mile south of Little Bay.

So far as the geology of Calhoun County has been studied it leads to the conclusion that the pottery clays will be found in a long series of outcrops skirting the Champanolle on both sides and along the west side of Moro Creek, following up the larger streams like Whitewater. They will be found also in the hillsides along the upper part of Locust Bayou and along the east side of Two Bayou toward its head. These clay beds vary in thickness and in character, but for all practical purposes they may be regarded as inexhaustible.

Clays available for ordinary pottery occur here and there in the wet slashes along the larger streams and along Ouachita River, but these deposits are limited in quantity and, as compared with the stratified Tertiary clays, are of inferior quality. It does not appear that the pottery clays of Calhoun County have ever been utilized, even for local purposes, and transportation facilities will need to be improved before the excellent clays of this county can be turned to much account.

CLAY COUNTY.

The only clays of economic importance found in Clay County are common brick clays. The most abundant brick clay is the loess, which occurs on the top and sides of Crowleys Ridge throughout the county. Along a narrow belt of country at the foot of Crowleys Ridge, on both sides, the loess has been reworked by the streams and forms a second bottom. The reworked product is very similar in appearance and composition to some phases of the loess. It usually has a more yellowish color, due to the presence of iron oxide obtained from the highly ferruginous sand underlying the loess on the ridge. Where the yellow second-bottom clay is constantly covered with water the iron oxide is largely leached out and the clay becomes a white glady soil.

The second-bottom land is much narrower on the west of the ridge than on the east. Patches of country between Cache and Black rivers are covered with white to gray buckshot clay. It is doubtless of the same age as the white glady land on the east side of the ridge. At various places in the county between the west edge of Crowleys Ridge and Current River the surface is covered with alluvial sand, which overlies the hardpan or buckshot clay where the latter has not been removed by the present streams.

The reworked loess at Pratt is being made into common building bricks by the Pratt Brick Company. This is the only plant in the county engaged in the manufacture of clay products.

CLEVELAND COUNTY.

GENERAL GEOLOGY.

The geology of the extreme northwestern part of Cleveland County is similar to that of Saline and Hot Spring counties; that of the central part is like that of Union and Calhoun counties, where there are so many good clays; while that of the southeastern portion is like that of Drew and Ashley counties. It is probable that there are many clay deposits in Cleveland County available for pottery, fire bricks, sewer pipe, etc.

The work in Cleveland County was done by Prof. G. D. Harris, who gives the following résumé of the geology of the lowest beds in the northwestern section:[a]

> A small portion of the northwestern quarter of this county is doubtless underlain by lignitic deposits. Records of well borings at Pinchback's mills, according to Mr. J. C. Simmes, of New Edinburg, show no traces of molluscan remains. The materials commonly passed through are sands and dark lignitic clay. In the vicinity of Cross Roads Church, about 4½ miles northwest of Kingsland, fossils belonging to the Jackson horizon were found in the form of casts and impressions in concretionary ferruginous sandstone. Wells near Kingsland and farther west are said to pass through 25 or 30 feet of sandy clay of a light-yellowish color, and then to encounter bluish clay or lignite. The bluish clay at some places continues for 30 feet or more, when it gives way to soft and sandy material that furnishes water in abundance.

The higher beds that cover all the central part of the county belong to the middle or Claiborne division of the Eocene (Tertiary), and are similar in the main to the beds of Calhoun and Union counties.

Below is given the record of a well on the land of J. B. Williams in the SW. ¼ SW. ¼ sec. 1, T. 9 S., R. 11 W.

Record of well on land of J. B. Williams.

	Feet.
Soil and sands	20
Joint clay	20
Clay with gypsum	10
Shells	10
Leaves	5
Dark-blue earth	12
Coarse white sand	4

On Mount Elba, just south of Bridges Bluff on Saline River, 3½ miles south of Toledo, the following section is exposed:

Section at Mount Elba.

	Feet.
Pebbly dark soil	2
Yellowish clayey sand	7
White chert pebbles	7
Light lignitic clay	3
Concealed to the water	15

Several other sections reported by Professor Harris in Cleveland County contain clays, but it is not clear whether they are valuable. Bed No. 4 in the following section reported by him appears to be one of promise. The locality is 5 miles southwest of New Edinburg, on the Moro Bay-Pine Bluff road.

Section near New Edinburg.

	Ft.	in.
Soil, sand, and a few pebbles	2	
Light, evenly laminated blue-gray clay	4	
Light-gray micaceous clay		6
Leaf-bearing bluish-gray clay	8	

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[a] Ann. Rept. Geol. Survey Arkansas for 1892, vol. 2, p. 57.

CLAY INDUSTRY.

There is an abundance of good brick clays over a large part of the county. The Leali Pressed and Fire Brick Company's brick plant at Kingsland, with a capacity of 20,000 bricks a day, has been in operation since about 1901. The plant manufactures dry-pressed, stiff-mud, and fire brick. Shale and common clay are used. The bricks are dried in a Standard steam drier, and burned in both up-draft and down-draft kilns, which hold from 75,000 to 400,000 bricks. The Raymond stiff-mud machines and the Berg dry-press machines are used. The former has a capacity of 40,000 and the latter of 20,000 bricks a day.

The company is preparing to move its plant to Little Rock, and will operate there under the name of The Southern Brick Company.

COLUMBIA COUNTY.

CLAY DEPOSITS.

All of Columbia County lies within the Tertiary-Quaternary region. The general geology of the county is favorable to the discovery of pottery, tile, sewer pipe, and refractory clays, and wherever such beds may be found the horizontality and uniformity of the geologic structure will make prospecting for them very simple.

The details of the geology of Columbia County have not been sufficiently studied to determine the precise geologic position or the geographic distribution of the more valuable clays, but clays of excellent quality will doubtless be found in abundance in the county. It seems most probable that they will be found not in the higher parts of the great watershed that runs through the middle of the county, but well down its sides and along the sides of the valleys of the larger streams.

The usual "deer-lick" clays are found in the wet slashes, but it is not thought that clays of this class are of sufficiently good quality or sufficiently abundant to warrant exploitation, except, perhaps, in a very limited way, to meet small local demands. The stratified clays are abundant and good, and when a good bed is found there is never much difficulty in determining its relations to the accompanying beds or in tracing it over the adjoining country.

On the road leading from Magnolia to Mount Holly, in the NE. ¼ sec. 3, T. 17 S., R. 20 W., there are some greenish-gray pottery clays, at least 3 feet of which is exposed. The upper part of this bed is discolored by iron, but the discoloration seems to be only superficial. Sandy fire clays are exposed in a gully on the side of the same road 9 miles east of Magnolia.

At a few places between this locality and Mount Holly there are small outcrops of pinkish sandy clays containing leaf impressions, but as a rule these beds are too sandy to make good pottery clays. The probabilities are, however, that the same beds at localities other than those examined may yield excellent clays, since they are of the same general character and appearance and contain the same fossil leaves as the pink fossiliferous clays used successfully at Perla switch, in Hot Spring County.

A quarter of a mile west of Mount Holly some promising-looking dove-colored clays are exposed at the side of the road. This clay, however, contains a few pebbles, and it may not prove to be of value. Beneath this gray clay are pinkish beds with leaf impressions.

The following is the record of a well dug by Mr. G. O. Bailey on his land near Magnolia, in the N. ½ sec. 34, T. 16 S., R. 20 W.:

Section of Bailey's well near Magnolia.

	Feet.
Surface soil	6
Cream-colored clay	15
Sand and pink clay mixed	3
Brown potter's clay	5

The second bed in this section contains a good many impressions of plants. The clay has not been analyzed, but its texture and color suggest its availability for the manufacture of good pottery. It contains 39.44 per cent of cream-colored sand. This sand is very fine, only 1 per cent of it being caught on a wire gauze having 100 meshes to the inch and 3 per cent on one having 150 meshes to the inch, the remainder passing through.

The third member of this section is of a light-pink color. It is very fine and clear of grit, but this pure part of the clay is so mixed with small pockets of rather coarse sand that in its present condition it is not available for fine pottery. The occurrence of this bed, however, is interesting, and suggests that a clean bed of excellent clay may yet be found. There is 29.08 per cent of clean white sand in clay No. 3, which includes that of the sand pockets as well. A large part of the sand, 36 per cent, is caught on a sieve having 100 meshes to the inch. In order to determine whether the body of it might not be kaolin the sand was washed from a sample of No. 3 and the water expelled by ignition. The loss was 9 per cent. The percentage of water in true kaolin is 13 per cent, while ordinary clays have 5 and 6 per cent. This can not, therefore, be regarded as a sandy kaolin, although it contains a higher percentage of water than ordinary pottery clays.

The brown clay in which the well ends is identical in color and texture and general appearance with the brown clays successfully used at Perla switch in the manufacture of pottery and fire bricks. It contains 28.92 per cent of fine light-brown sand, the lower brown clay at Perla switch containing 21.9 per cent. All the sand in this brown clay is very fine, only a little more than 1 per cent of it being caught in a sieve having 150 meshes to the inch, the remainder passing through. This lower bed, like that at Perla, contains many impressions of leaves and stems of plants; indeed, the whole section seems to be very similar to the clay pits at that place.

It is reported that clays similar to those found in Bailey's well have been passed through in digging several wells in the neighborhood, and that in some of them the lower brown clay has been penetrated to a depth of 10 or 12 feet without having been passed through.

CLAY INDUSTRY.

The McIntyre Company has a small brick plant at Magnolia. The plant was established in 1884. Surface clay is used, from which is made a red common building brick. The bricks are molded by hand, dried in the open air and sunshine, and burned in an up-draft kiln. About three days are necessary to dry the bricks sufficiently to place them in the kiln; nine days are required for burning. Wood is used as fuel. The output is 5,000 a day. The molds are 8⅓ by 4¼ by 2½ inches.

CONWAY COUNTY.

GENERAL GEOLOGY.

The general geology of Conway County is the same as that of Faulkner County, and the clays of the two counties are therefore of the same character and have the same geologic distribution.

The surface rocks in Conway County, except the later deposits along Arkansas River, are entirely in the "Lower Coal Measures." The hard rocks are alternate sandstones and shales that lie nearly flat in the northern part of the county and are thrown into gentle folds in the southern part. The ridges here, as in other portions of the State, are capped by sandstone or are made up entirely of sandstone, while the valleys are generally underlain by shales.

Starting about 2½ miles west and a little north of Morrillton, the Morrillton anticlinal fold of the rocks runs due east to Cadron Creek, crossing that stream in sec. 8, T. 6 N., R. 14 W. The group of parallel ridges and valleys involved in this fold have a width of 3 miles in Conway County. The relations of these ridges to one another are not apparent to anyone passing across the county on the railway, because the railway does not cut across them, but follows the valleys, and is therefore parallel to the lines of structure.

CLAY DEPOSITS.

Varieties.—The principal clays of Conway County are of the following four varieties:

1. The clay shales and the clays derived directly from them by disintegration.

2. The limonitic buckshot clays.
3. The leached clays of the slashes.
4. The alluvial chocolate clays of the second bottoms along Arkansas River.

Clay shales.—The clay shales are interbedded with the sandstones and are, in the main, similar in character and distribution to those of Faulkner, White, and Pulaski counties. Where they have the proper composition they are available for the manufacture of paving bricks, sewer pipe, and fire-clay products. No chemical analyses have been made of specimens of shales of White County, but the analyses of the Round Mountain shales of White County and of the Little Rock shales of Pulaski County may be accepted as indicating in a general way the character of the clay shales to be found in Conway County.

Buckshot clays.—The buckshot clays cover a large part of the higher valleys of the county. These are used for making common bricks, but owing to the presence in them of the buckshot or small nodules of iron the bricks are often covered with dark-brown spots. These spots are likely to be produced in any well-burned bricks made of the buckshot clays.

Leached clays.—The leached clays are probably only modifications of the buckshot clays. Both the leached clays and the buckshot clays are derived indirectly from clay shales, and chemically altered by weathering and leaching. Where waters charged with organic acids stand for a long time in shallow pools in the slash lands, the underlying clays are often leached of their iron and made available for the manufacture of coarse pottery. Such clays are found in Conway County in the wet places on the second bottoms of the Arkansas River, Point Remove Creek, and Cadron Creek.

The alluvial chocolate clays of Conway County are in every respect similar in character and topographic position to those of Faulkner County.

Old Lewisburg terrace clay.—At Old Lewisburg, 1 mile south of Morrillton, a red clay caps all the elevations. This clay has a maximum thickness of about 20 feet and shows four distinctly colored beds. As seen at a point 250 yards southeast of the ferry, the exposures in a deep gully are as follows, beginning at the top:

Section at Old Lewisburg.

	Feet.
1. Flesh-colored clay containing much sand	7
2. Dark-red plastic clay containing a few small siliceous concretions	4–5
3. Pinkish clay, with numerous small siliceous concretions	3–4
4. Yellowish and mottled sandy clay overlying the black shale that outcrops along the river south of the ferry	4–5

The dividing line between these beds of clay is fairly distinct, though they grade slightly into one another. Bed No. 2 contains less sand, apparently, than any of the others. Bed No. 4 is evidently a decomposition product of the black shale that underlies the region about Old Lewisburg and that crops out along the river bank above and below the ferry. This shale contains much sand, and at some places, as just above the ferry, it contains beds of shaly sandstone. It has a dip of 25° S. Beds 1, 2, and 3 are foreign to this locality and are not derived from this shale bed.

The whole site of the town of Old Lewisburg is underlain by the clay mentioned in the section, except where these beds have been cut through by gullies. Bricks have been made from the clay at the south edge of the town of Old Lewisburg. This clay has about the elevation of No. 1, but the clay exposed in the old pit did not show so much sand as bed No. 1 in the gully where the section was taken. The clay of the pit is red. These bricks are reported by Mr. Morloch, who helped to tear down some of the buildings made from them, to be soft and crumbling. No bricks have been made here since Old Lewisburg was in its prime, many years ago.

Clays south of Morrillton.—The ridges south of Morrillton are each formed by a heavy bed of sandstone, dipping south at an angle of 25°. Between these two sandstone ridges is a black, gritty shale, forming a red brick clay. The shale bed is about 275 feet thick.

This clay resembles that of the valley in which Morrillton stands. The clay in this valley is found mostly on the north slope of the south ridge and on the south slope of the north ridge. Where the same clay occurs in the bottom of the valley it contains more sand than it does on the slopes of the ridges.

Brick clays at Morrillton. About 150 paces west of the public school building in Morrillton, on the north slope of the ridge, is a bed of reddish plastic clay, from which bricks have been made. This clay is sticky, but contains small iron "buckshot" nodules and is sandy, though the amount of sand is not excessive. This same clay bed extends all along the northern slope of this ridge, which is the first one south of the town. It is uniform in color and plasticity and in the amount of buckshot it contains. It is the product of the decomposition of the black, sandy, southward-dipping shale that underlies the whole valley in which Morrillton is built. This [illegible] clay at no place appears to have a thickness of more than [illegible] feet. The clay formerly used at W. M. Morloch's brickyard, [illegible] more than half a mile east of the railway station at Morrillton, [illegible] is only 1 to 2 feet thick, [illegible] coming close to the [illegible] seen on the surface [illegible] The shale that [illegible] as that forming the clay at the base of the ridge immediately south of the town, but geologically it is about 200 feet lower. The character, color, and plasticity of the clay are the same as those of the clay west of the public schoolhouse. This plant has now gone out of business.

One mile northeast of Morrillton, at a place where the road runs northward past Thomas D. Hawkins's house, a 2-foot bed of red clay, with little sand, is cut through by the road. Where the road crosses the point of the ridge that rises toward the east from the northeast edge of the town there is a similar red clay.

Red clay like that at the localities described above is to be found on nearly all of the slight elevations in the valley and near Morrillton. The bed does not exceed a very few feet in thickness at any place. It is derived from the bed of black gritty shale that underlies this valley and is all of about the same color, has the same amount of sand, and contains much iron in the form of buckshot nodules. It makes a very good quality of brick so far as hardness and durability are concerned, though its color is somewhat injured for special uses by the black iron blotches.

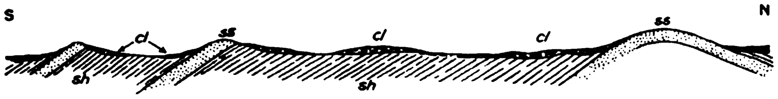

FIG. 6.—Section east of Morrillton. *cl*, Clay; *sh*, shale; *ss*, sandstone.

This clay is good for common bricks or common tiles, but would not be available for sewer tiles, nor can it be used for any other than common bricks.

The shale that makes up the valley is apparently about the same throughout in thickness, color, hardness, and percentage of sand, and yields a pretty uniform residuary clay. The bed of shale is from 550 to 600 feet thick, and under the town of Morrillton and east of it dips south, but turns over the nose of the anticline at the northeast corner of the town and dips north. A north-south section 1 mile east of Morrillton, from the sandstone in the south side of the anticlinal nose to the second ridge south of Morrillton, is shown in fig. 6.

This section represents the thickness of the rocks about 1 mile east of Morrillton, and shows how the clay occurs on the shale in Morrillton. Where the section is taken the clay is mostly eroded away at the north side. At present no clay industries are reported from Conway County.

CRAIGHEAD COUNTY.

GENERAL GEOLOGY.

The eastern half of Craighead County is occupied by St. Francis River, the Hatchie Coon sunk lands, and a broad belt of low, undrained swamp lands, which extend westward to the narrow fringe of post-oak lands adjacent to Crowleys Ridge.

The country east of Lake City is made up of sunken lands that are subject to frequent overflow, except along some of the slightly elevated areas which are covered with "sandblows." The sandblows consist of fine white sand which has accumulated in small, more or less separate areas and is surrounded by darker colored loam or sand. The country from Lake City to Nettleton is a flat buckshot soil, with a growth of scrubby willow oak, post oak, black oak, and an occasional hickory, white oak, and persimmon. The long-trunked sweet gum and cottonwood are entirely absent.

In the southern part of Craighead County Crowleys Ridge is but one-half mile across, narrower than at any other point between the Missouri line and Helena except where it is cut in two by L'Anguille River in Lee County. North of Jonesboro it widens out, and near the northern border of the county it is broader than at any other point in the State.

The white buckshot land extends westward from the foot of Crowleys Ridge to within about one-half mile of Cache River. Cache River bottom is from 6 to 10 feet lower than the buckshot land to the east, and along the railroad in the northwest corner of the county it is 1 mile wide.

The top of the ridge throughout the county is generally covered with buff-gray to yellowish loess. This is underlain by coarse gravel, which in places has become cemented into a compact conglomerate.

In the northern part of Craighead County the eastern slope of the ridge is more gentle than on the western side. The western slope is very precipitous and affords a better opportunity for the study of the stratigraphy of the ridge.

The following section, obtained 4 miles west of south of Lorado, in Craighead County, affords the best exposure of the Tertiary in the county.

[illegible] Law place.

	Feet.
[illegible]	40
[illegible]	2- 8
[illegible] places has [illegible]	15
[illegible] clays	15

A continuation of the Tertiary strata in Crowleys Ridge is given below, in a general record of the deep wells at Jonesboro:

Record of deep wells at the city water plant, Jonesboro.

	Ft.	In.
Red clay (loess)	20	
Gravel, mixed with red clay	4	
Joint clay	10	
Coarse yellow sand		10
Pipe clay	25	
Gumbo	10	
Sand, very fine on top, grading downward into coarse sand and gravel, water bearing	60	
Very tough gumbo	50	
Blue mud with iron concretions, extending downward to 1,200 feet.		

CLAY INDUSTRY.

Jonesboro and vicinity.—The brick industry of Craighead County is confined to the vicinity of Jonesboro, on Crowleys Ridge, where five plants have been established for the manufacture of wet-mud and dry-pressed bricks.

The following is an analysis made from one of the brick clays at Jonesboro.

Analysis of brick earth from the surface at Jonesboro.

[Dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	79.49
Alumina (Al_2O_3)	8.71
Iron (Fe_2O_3)	3.43
Lime (CaO) Magnesia (MgO) (by difference) Alkalies	2.10
Manganese (MnO)	2.44
Loss on ignition	3.83
	100.00
Air-dried sand in air-dried clay	33.40

Jonesboro Brick Company.—One of the largest plants in the State is that of the Jonesboro Brick Company, where soft-mud and dry-pressed bricks are made. The machines for molding the two kinds of bricks are placed under the same shed and run by a central power plant.

The clay used for the dry press is loaded into carts at the pits by hand and drawn to the dry shed, where it is permitted to remain for months before it is made into bricks. When sufficiently tempered it is molded into bricks and set in the kiln. The capacity of the machine is 20,000 bricks a day. The bricks are burned in stationary up-draft kilns, and it requires twelve to fourteen days to burn them.

When thoroughly burned the bricks are of a cherry-red color and are considered substantial.

The wet-mud machine has a capacity of 30,000 a day, but it requires just twice the number of men to operate it.

The clay used for making the wet-mud bricks is the same as that used in the dry-press machine, except it is not stored in sheds and tempered before it is used. It is hauled from the pit in carts and dumped into small cars, which are drawn up an incline by means of a wire rope attached to a large drum. The cars are unloaded into a bin and fed into the machine by means of a belt with cups upon it. The bricks are removed from the machine and dried on pallets in covered racks. It requires from four to six days for drying, and seven to nine days for burning. Stationary up-draft kilns are used. Wood is used exclusively for burning.

Barton Lumber and Brick Company.—On the lot adjoining the Jonesboro Brick Company's plant, near the depot of the Jonesboro and Lake City Railroad, is the plant of the Barton Lumber and Brick Company, where both wet-mud and dry-pressed bricks are made. The bricks are molded by steam and the wet mud is dried by air in covered racks. They are burned in up-draft clamp kilns, and require about eight days for burning. A kiln that is built 34 bricks high is burned until it settles about 8 inches.

Saxe Brick and Tile Company.—At the time it was visited in June, 1905, the plant of the Saxe Brick and Tile Company was under construction. When completed the plant will have a capacity of 10,000 4 inch tile a day, or its equivalent. Tile will be the principal product if it can be made from the clay. Both soft- and stiff-mud machinery have been installed. The American Clay Worker end-cut automatic machine has been erected for making stiff-mud bricks and tile. Both open air and steam-heating sheds will be used for drying the product. Down-draft clamp kilns are to be used, wood and coal serving as fuel.

Patrick Brothers Brick Company.—The plant of the Patrick Brothers Brick Company was established in 1905 for the manufacture of soft mud building bricks. The bricks are made from the common, surface reworked loess clay. They are dried in the open air by means of the pallet and rack system. It requires from six to nine days for drying and from six to seven days for burning. Wood is used for burning. The capacity of the machine is 12,000 to 15,000 bricks a day. The size of the green bricks is 9 by 4⅜ by 2½ inches. The total shrinkage in drying and burning is ⅜ by ½ by ¼ inch.

Logan & Collans plant.—No particulars of the Logan & Collans brick plant were obtained.

CRAWFORD COUNTY.

GENERAL GEOLOGY.

The general geology of Crawford County is similar in the main to that of Franklin County on the east and to that of Sebastian County on the south. The southern part of the county—a little more than half of it—is covered by the upper division of coal-bearing rocks of the Carboniferous system. The northern part is made up of rocks that underlie the coal-bearing beds. Most of the rocks of the northern part of the county dip gently toward the south. The coal-bearing rocks are chiefly sandstones and shales, and the valuable clays of the county are to be looked for in these clay shales or in the clays formed by their disintegration. Other kinds of clays of later age that are spread over the lowlands will be spoken of under the head of brick clays.

In sec. 24, T. 9 N., R. 32 W., the following geologic section is exposed along Arkansas River in the hills north of the town of Van Buren.

Section in hills north of Van Buren.

	Feet.
Gray sandstone on hilltop	20
Slaty shales	120
Hard gray sandstone	20
Dark slaty shales	170
Sandstone	4
Dark shale at base.	

Especial attention is directed to this section as showing the enormous thickness of the shales of Crawford County in the vicinity of Van Buren, on the very banks of Arkansas River. The importance of the section and the thickness of the shales will be seen when it is realized that many of these shales are available for the manufacture of paving bricks, sewer pipes, and certain fire-clay products It should be remembered also that these same beds spread over a considerable part of Crawford County.

One other section may be given as a type of Crawford County rocks and their sequence. This section is on the east part of the hill in the SW. ¼ sec. 12, T. 10 N., R. 29 W.

Section in SW. ¼ sec. 12, T. 10 N., R. 29 W.

	Feet.
Brown sandy shale	15
Flaggy sandstone	10
Sandy shales	10
Thin-bedded sandstone	10
Sandy shale	5
Massive sandstone	10
Concealed	40

	Feet.
Dark-gray shale	20
Compact sandstone	20
Shale	20
Concealed to the creek bed	80

Some of the shales in the above section are sandy, but sandy shales are liable to become argillaceous as the beds are traced from one locality to another.

CLAY DEPOSITS.

Character of material.—Especial emphasis should be laid upon the fact that the value of the clay shales of Crawford County is untested. Not long ago it was supposed that only plastic clays were available for the manufacture of paving bricks. The experience of the brickmakers of Fort Smith, Ark., as well as that of manufacturers at Cheltenham, Mo., and other places, shows that many shales are available for brickmaking when properly treated. The localities mentioned here must not therefore be regarded as the only ones in the county, or even the most important ones. They are merely a few beds that were noted in the course of work done along other lines of investigation. The notes on clays in section 10 are by C. E. Siebenthal; the remaining notes on the clays of Crawford County are by William Kennedy.

Plastic clays.—A plastic cream-colored clay, somewhat iron stained, was found in digging a well in the SW. ¼ SW. ¼ sec. 10, T. 10 N., R. 30 W., on George Meador's place. The bed is said to be about 8 feet thick. The same clay is said to occur in many of the wells in this section. It was formerly used for the manufacture of smoking pipes.

A bluish-mottled plastic clay is exposed in the NE. ¼ SW. ¼ sec. 8, T. 10 N., R. 30 W.

Fire clays.—The disintegrated shales exposed in the various localities in the neighborhood of Alma afford a material suitable for the manufacture of articles requiring a clay of rather high fusing point.

Near Fine Spring, in the NE. ¼ SW. ¼ sec. 18, T. 10 N., R. 30 W., the clay is divided into an upper bed of yellow clay, 4 inches thick, overlying a bed of dark-blue clay. The thickness of this blue clay is not known, but it is said to have been dug into by Mr. W. M. James, the owner of the land, to a depth of 7 feet. .

This same kind of clay is also found in the E. ½ NW. ¼ SE. ¼ sec. 18 and the NW. ¼ SW. ¼ sec. 17 of the same township and range. The deposit at Fine Spring is in the side of a hill, and is so covered with detritus as not to be visible without digging. This detritus consists for the most part of blocks of sandstone and shaly fragments derived from beds overlying the clay. These overlying beds have a thickness of more than 50 feet.

To obtain this clay it will be necessary to resort to mining. The thickness of the material will favor this, and there is an abundance of timber in the neighborhood for mining purposes. It is not possible at present, however, to foresee the depth to which the soft clays may reach before assuming their normal condition as shales. The deposit lies within 2½ miles of Rudy station, on the St. Louis and San Francisco Railroad, and 5 miles from Alma, on the St. Louis, Iron Mountain and Southern Railway. This clay is said to have been tested at St. Louis and at Fort Smith, but no satisfactory information could be gained regarding the parties interested in or making the tests. The dark clay has been tested in the laboratory of the Arkansas Geological Survey for loss in burning. The clay burned to a whitish-yellow color and the loss due to the burning amounted to 9.71 per cent.

Van Buren clays.—The most valuable soft clays at and around Van Buren are those formed by the disintegration of the Carboniferous shales. The localities mentioned below are the ones at which the deposits appear to be most suitable and most advantageously situated for working.

About 3 miles northeast of Van Buren, in the SW. ¼ NW. ¼ sec. 16, T. 9 N., R. 31 W., close to Hendrick's coal opening, is a light-blue clay which burns to a bright yellow. Small test pieces of ware said to have been made from this clay show good, sound texture and a bright yellow color. No definite information, however, could be obtained regarding the parties who made these tests

The bed varies in thickness from 18 inches to 6 feet. The clay was tested for brickmaking purposes at Fort Smith by Pendell & Morrison for Mr. L. D. Middleton. Eleven carloads of this clay were manufactured into 4,500 bricks, which were used by Mr. Middleton to line his limekiln at Fayetteville. The limekiln was kept burning for twenty-seven consecutive days. At the end of that time the bricks were examined and found in perfect order, though highly vitrified. In the manufacture of these bricks Messrs. Pendell & Morrison were troubled by the stickiness of the clay, and in order to work it in their machine were obliged to mix with it the sandy, brownish-yellow clay used in making their ordinary building brick. No definite proportion was observed in the mixture, however, only enough of the sandy clay being added to render the material workable.

Analyses of the clays used in making these bricks are given below.

Analysis of clay from SW. ¼ NW. ¼ sec. 16, T. 9 N., R. 31 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	64.63
Alumina (Al_2O_3)	24.71
Iron (ferric) oxide (Fe_2O_3)	3.71

Lime (CaO)	0.31
Magnesia (MgO)	.41
Potash (K_2O)	2.03
Soda (Na_2O)	.94
Loss on ignition	6.52
	102.26
Sand in specimen, very fine	3.43
Water at 110°-115° C	3.02

The following analysis gives the combination of the sandy clay mixed with the above, obtained from Messrs. Pendell & Morrison's brickyard:

Analysis of clay from Pendell & Morrison's yard, Fort Smith.

[Brackett & Smith, analysts.]

Silica (SiO_2)	76.26
Alumina (Al_2O_3)	11.74
Iron (ferric) oxide (Fe_2O_3)	4.54
Lime (CaO)	.39
Magnesia (MgO)	.79
Potash (K_2O)	1.28
Soda (Na_2O)	.98
Loss on ignition	3.82
	99.80
Sand	47.79
Water at 110°-115° C	3.71

The clay from Van Buren is said to have been tested by the Laclede Company at Cheltenham, Mo., and by the Clinton Pottery Company at Clinton, Mo., but the results of these tests have not been ascertained.

On Bridge's place, in the SE. ¼ NW. ¼ sec. 36, T. 10 N., R. 32 W., about 3½ miles from Lily station on the St. Louis and San Francisco Railroad, is a light-blue clay which burns to a yellow.

Mr. Meyers sent some of this clay to St. Louis, where it was made into biscuit ware for decorative purposes. The ware has a bright yellow color. The name of the manufacturer of the ware could not be learned.

Clay from this locality is said to have been tested at St. Louis, by the Clinton Pottery Company at Clinton, Mo., and by Messrs. Sailor & Bevens at Weir City, Kans., the last-named firm having used it for the manufacture of retorts. The analysis is given below.

Analysis of clay from Bridge's place, sec. 36, T. 10 N., R. 32 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	67.64
Alumina (Al_2O_3)	21.57
Ferric oxide (Fe_2O_3)	2.48
Lime (CaO)	.27

Magnesia (MgO)	0.62
Potash (K_2O)	1.63
Soda (Na_2O)	.57
Loss	5.53
	100.31
Sand.	
Water at 110°–115° C	2.85

The same class of clay is said to have been found in wells in the E. ½ N. ½ SW. ¼ sec. 36, and also in a well 10 feet deep in the E. ½ NW. ¼ sec. 31, T. 10 N., R. 31 W., where it is reported to be 4 feet thick.

An excavation made in the SE. ¼ NE. ¼ sec. 17, T. 9 N., R. 31 W., by J. L. Rea, in prospecting for clay similar to that found on the western side of sec. 16, passed through about 10 feet of Carboniferous shales, but encountered no soft clay.

In digging foundations for a house on Mrs. Moore's farm, near Lees Creek, in sec. 15, T. 9 N., R. 32 W., a fine white clay was discovered under the creek bottom land. On the road from Van Buren to Dora station there are several exposures of yellow clay, in places overlain by red clay. At Mrs. Moore's house and along the northern half of the southeast quarter of the section the red clay overlying the yellow has an average depth of about 2 feet.

In the NE. ¼ SW. ¼ sec. 17, T. 9 N., R. 32 W., a well 10 feet deep passed through 18 inches of fine gray clay at the bottom of the well.

In the SW. ¼ NE. ¼ sec. 30, T. 9 N., R. 31 W., the underlying clay is mottled, and has a thickness of 3 feet. On the east side of the hill on which Mr. Meyers's house is situated a stiff dark-red clay overlies the mottled clay. This red clay is similar in appearance and texture to that in the N. ½ SE. ¼ sec. 15, T. 9 N., R. 32 W.

Near the Van Buren freight depot of the St. Louis and San Francisco Railroad the blue and red clays rest directly upon black shale.

In the SE. ¼ SW. ¼ sec. 18 and the SW. ¼ NE. ¼ sec. 19, T. 9 N., R. 31 W., the railroad cuts expose a brown clay resting upon a mottled red and yellowish-white clay.

Brick clays.—At the western end of the town of Alma there is an area covered by a brownish brick earth showing in places a depth of 5 to 7 feet. It lies in T. 9 N., R. 30 W., in the following sections: SW. ¼ SW. ¼ sec. 5; SE. ¼ SE. ¼ sec. 6; the greater part of E. ½ sec. 7; the west side of sec. 8; and the land extending southward to the creek in the SW. ¼ NW. ¼ sec. 17.

In the SW. ¼ NW. ¼ sec. 17 the brownish-yellow brick earth is underlain by a yellowish-blue clay, which rests upon Carboniferous shale. Both clays contain nodules of iron, which become more plentiful toward the base of the beds.

From the eastern end of the town of Alma to Dyer station, in sec. 36, T. 10 N., R. 30 W., on the St. Louis, Iron Mountain and Southern Railway, this brownish-yellow brick earth lies on both sides of the railway track. At Dyer it has a yellowish color. It is exposed in the cuts east of Dyer as far as Mulberry.

No bricks are made at Alma. In 1886 two or three kilns were made from the brick earth in sec. 9 for local use by Hon. M. F. Locke. They were hand made and burned to a gray color and are spotted with iron.

The fuel used at Alma is chiefly wood, but coal can easily be obtained from Sullivant's mine, 2 miles from town. Wood ranges in price from $1.25 to $2 a cord, and coal costs $2.50 a ton delivered.

On the west bank of Clear Creek, at the place where it is crossed by the St. Louis, Iron Mountain and Southern Railway, 1½ miles west of Alma, the following section is exposed:

Section on Clear Creek, near Alma.

Yellow brick clays.
Mottled fawn colored and yellow clay.
Waterworn cobbles.
Black shales of the "Coal Measures."

The yellow and mottled clays of this section aggregate about 25 feet in thickness. These clays become thinner west of Clear Creek.

Bricks were formerly made at Van Buren, but work there has been discontinued. They were manufactured from a brownish clay found lying between the line of the St. Louis and San Francisco Railroad and the shale escarpment to the west. This ground lies chiefly in the SE. ¼ sec. 24, T. 9 N., R. 32 W., and the SW. ¼ sec. 19, T. 9 N., R. 31 W. The clays used for brickmaking are similar to clays in other districts in the western part of the State. The beds are divided by a colored line into an upper and a lower division. The lower division is darker and contains more iron than the upper. This upper division is a light-brown sandy clay and is about 2 feet thick in the vicinity of Van Buren.

CRITTENDEN COUNTY.

Crittenden County lies entirely in the overflowed land of the Mississippi, its surface standing but a few feet above low-water mark along the river. The lowest point along the Kansas City, Fort Scott and Memphis Railroad (Frisco System) between Memphis and Deckerville is 223 feet and the highest point 228 feet above sea level.

The surface of the county is marked by small lakes, abandoned stream channels, and sluggish streams. Near Marion, Grassy Lake, and other places there are deep depressions, doubtless representing former channels of the Mississippi. The one north of Marion is about 1 mile wide and has trees growing in it 3 to 4 feet in diameter. The oxbow shape of the depression and its continuation across the country indicate that it is an old river channel and not simply a depression.

The old channel at Grassy Lake is about 1 mile wide and the level of the water is 20 feet or more below the level of the country at Crawfordville.

Most of the soil of the county is composed of sand and silty clay, resulting from repeated overflows of Mississippi River. At no place is the material suitable for making common bricks unless the yellowish surface loam that occurs at a few places near the center of the county may be used for this purpose. Crawfordville and Earl are situated on small ridges which are said to extend in a northeast-southwest direction. These ridges contain at the surface a thin surface loam which is somewhat similar to the yellow loam in the prairie lands west of Crowleys Ridge.

At present no bricks are manufactured in the county.

CROSS COUNTY.

GENERAL GEOLOGY.

Crowleys Ridge extends through Cross County near the center in a north-south direction. The eastern half of the county is a low bottom country traversed by St. Francis River and St. Francis Bayou. Almost the entire area east of the ridge is covered by alluvial deposits. St. Francis Bayou hugs the foot of Crowleys Ridge, which forms a steep erosion scarp across the county.

The geology of the county is best studied along the steep eastward-facing bluffs of Crowleys Ridge. The lower Tertiary strata outcrop at the base of the ridge and extend 65 to 75 feet up its sides; above this comes 18 to 20 feet of waterworn pebbles and coarse sand, which corresponds to the Lafayette of Mississippi and Tennessee, and is but roughly stratified. This in turn is overlain by loess, with a maximum thickness of 50 to 60 feet.

The following is a section along the creek east of Wynne, at a point three-fourths of a mile southeast of the 3-mile post on the railroad:

Section 3 miles east of Wynne.

	Feet.
1. Loess capping top of hill; in places stratified and containing numerous lime concretions and land shells; lower 5 feet contains sand and pebbles derived from underlying Lafayette...	18
Unconformity; top of Tertiary.	
2. Coarse oxidized sands and pebbles, which correspond to the Lafayette of Mississippi and Tennessee	18
3. Gray to lemon-colored sand, with thin layers of pale-gray sandy clay	20-22
4. Brown lignite and lignitic clay	1
5. Clay sand similar to No. 4	8
6. Landslide, which has covered the rest of the hillside to base bluff	30

The bed of the creek one-half mile north of the above locality is 65 feet below the top of the Tertiary beds in the above section. The Tertiary strata of the section at the creek for 30 feet above the water, forming a continuous section with the one given above, consist of dark-blue clay interstratified with coarse sand, which contains large iron concretions 1 foot or more in diameter. Besides the iron there are numerous smaller lime concretions. The blue clay where exposed in the bluff sloughs off in large, vertical slabs. It contains more or less mica, selenite, and alum salts. Thickness, 30 to 35 feet.

On the west side of Crowleys Ridge the slope is more gentle and the Tertiary strata are covered by talus from the ridge. The surface material in the adjacent level land is gray to yellowish sandy clay, which is used for brick manufacture. In the town of Wynne this surface clay is penetrated in the wells at a depth of 40 feet.

CLAY DEPOSITS.

The most important clay in the county is the common brick clay. The loess and yellow loam on the top and the west slope of Crowleys Ridge form an inexhaustible supply of common wet-mud and pressed-brick clays.

One mile east of Wynne the following section in the railroad cut shows the variation in the color and character of the loess:

Section in railroad cut 1 mile east of Wynne.

	Feet.
Light-gray to buff loess	10
Reddish loess containing fine sand	20-30
White loess with more or less scattered pebbles and sand	5-10

The reddish loess would doubtless be better adapted to the manufacture of brick than the upper or lower layer. It contains a large amount of iron oxide and would burn to a bright red. Where the calcareous loess is used without mixing it with sandy clays there is great danger of getting the bricks too soft by adding too much water.

There is a bed of good sewer-pipe and tile clay at the base of a section in the Tertiary of Cross County near the village of Cherry Valley. The locality is in the NE. ¼ NW. ¼ sec. 23, T. 9 N., R. 3 E. The clay is exposed in the bottom of the creek to a depth of 3 feet, and extend downward to an unknown depth. It is a fine light-drab clay, unctuous to the touch and apparently suited to the manufacture of sewer pipe. It is more like potter's clay than any other clay that has been found in the Crowleys Ridge country. There is a similar deposit at the base of the section exposed at Double Head Bluff in St. Francis County, near the water level. The locality is in the NW. ¼ NW. ¼ sec. 18, T. 5 N., R. 4 E. It is much thicker here than at Cherry Valley, on the opposite side of Crowleys Ridge, and it is possibly identical with it. Neither of these clays are fire clays and could not be successfully used for fire brick.

CLAY INDUSTRY.

The plant of the Wynne Brick Company is located at the foot of Crowleys Ridge, about one-half mile east of the station at Wynne. The reworked clay from the ridge is used in the manufacture of brick. Common soft-mud bricks are made, which are pugged and molded by machinery. They are dried under covered racks in the open air. Up-draft scove kilns are used for burning the bricks. The kilns hold from 100,000 to 250,000 bricks. It requires about eleven days to burn the brick, using one-fourth of a cord of wood and one-half ton of coal per thousand bricks. The clay is very easily overburned. Near the eyes in the kilns the bricks are often burned to a vitreous mass, while on the outer edges they are not burned hard enough. The loss in burning and hauling is estimated by the superintendent to be about one-third. The size of the molds used at this plant is 9 by 4¾ by 2½ inches. When burned the bricks measure about 8 by 4 by 2¼ inches.

The water used for the boiler comes from a bored well 250 feet deep. It stands within 100 feet of the surface.

DALLAS COUNTY.[a]

GENERAL GEOLOGY.

Dallas County is in the south-central part of the State, entirely within the Tertiary area. The rocks here, as in other portions of the Tertiary area, are soft, horizontally bedded clays, sands, and brown coals, variously interstratified, the whole overlain by coarse sand and gravel of varying thickness. The northwest quarter of the county is the highest, and from this region the surface slopes eastward and southward. The topography is of the undulating character that is common in regions covered with soft and easily eroded strata.

CLAY DEPOSITS.

CHARACTER OF THE CLAYS.

Potter's, fire, and brick clays are found in Dallas County in practically unlimited quantities. That the potter's clay is of good quality is shown by the fact that the ware made from this clay compares favorably with that made from clays worked at other localities. It has been used locally to a small extent as fire clay in laying up furnaces, etc. It has also been used as a whitewash, and when so used it gives a smooth coat of a pleasing, slightly bluish tint. For such purposes it is dissolved in buttermilk and boiled, and it is claimed that the composition furnishes about as durable a coating as that made with lime.

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[a] The matter relating to Dallas County is taken almost entirely from C. E. Siebenthal's report on this county in Ann. Rept. Geol. Survey Arkansas for 1891, pp. 278 et seq.

It has been found that potteries here can not compete, except in local markets, with potteries that are situated on railways and that work clay equally good. The future of the pottery industry in Dallas County therefore depends on facility of transportation of the product to markets.

CLAY BEDS WORKED.

Since the stratigraphy of these clays has not been worked out in sufficient detail to permit their discussion in natural sequence, it is perhaps best first to describe in detail those beds which have at one time or another been opened and worked, together with those of which the clays have been analyzed, and afterward to take up the miscellaneous outcrops and well records.

Butler clay.—The first clay bed opened in Dallas County was probably that which became known as the Butler bed. This bed is in sec. 4, T. 8 S., R. 15 W., about 400 yards east of the southwest section corner, on the west bank of a head of East Tulip Creek, at an elevation of 350 feet above sea level. Clay has not been taken from this pit for many years, and the only traces of early operations are seen in a hollow that was scooped out of the creek bank and has since filled with débris. In a gully about 100 yards north of this opening 4 feet of lignite outcrops and is overlain by a plastic white clay, similar to Tall's clay, which occurs about one-half mile north of this place. (See p. 76.) Clay was also taken from an old field about one-fourth mile south of the opening first mentioned, but the old pit has long been filled with débris.

Cheatham clay.—The next bed opened was the Cheatham bed, on Dry Tulip Creek, in the NW. ¼ NE. ¼ sec. 22, T. 8 S., R. 15 W. The clay was worked back a little way from the creek on a small drain, but no exposure can now be seen on account of the débris that conceals the bed. On the creek bank about 100 yards south of this locality the following section is exposed at an elevation of 260 feet above sea level:

Section near Cheatham's upper bed, Dry Tulip Creek.

	Feet.
Soil and gravel	2
Argillaceous shale	4
Soft sandstone	3½
Clay and shale	2
Lignite	1
Stiff clay (partly concealed)	4
Lignite	3-4
White, plastic clay	5

Clay has also been taken from a bluff on the west side of the creek one-half mile farther south, in the southwest quarter of the northeast quarter of the same section. The elevation above sea is 255 feet. From 6 to 8 feet of gray joint clay is exposed. The lignite bed of the upper bank was not observed here, but the upper part of the bluff is covered with débris. The clay is fine grained, with some grit, and clings strongly to the tongue. This clay has been used more extensively than any other in the county and has uniformly been pronounced good by potters.

Bird clay.—The Bird clay bed outcrops on a hillside near one of the small streams flowing from the south into Cox Creek, in the NW. ¼ NE. ¼ sec. 6, T. 7 S., R. 15 W. The same clay outcrops farther west, around the head of Cox Creek, and farther east along the breaks of the hills skirting the north edge of Gum Bottom. The portion of the bed that was worked stands 390 feet above sea level, but clay of apparently the same quality outcrops in places in the drain all the way up to the elevation of 440 feet. This would indicate that the bed is about 50 feet thick. At the pit about 15 feet is exposed. This clay is said to have the disadvantage of being difficult to dry without cracking. This fault could be remedied by a judicious admixture of other clays. When freshly exposed the clay is light bluish in color and very plastic. It is very fine grained and contains but little grit.

Analysis indicates that this is a good clay, the silica and alumina being in good proportion and the percentages of the fluxes very moderate.

Welch clay.—This bed is located in the SE. ¼ SW. ¼ sec. 6, T. 8 S., R. 15 W. The bed stands 355 feet above sea level, making it correspond very closely in elevation with the Butler clay, described above. The bed has been dug into for 7 or 8 feet, and the quality of the clay improved and its color became lighter as greater depth was reached. The clay occurs in angular lumps, is light bluish gray in color, and is very fine grained, with little grit. Mr. Welch reports that the joint spaces are filled with a crystalline substance somewhat resembling common salt, and that particles of this substance become embedded in the ware and make blisters when burning. Samples of ware made from this clay are hard and close bodied. It burns to a gray slate color when perfectly done, the softer pieces varying from yellow to brown.

Mr. Welch reports that he is unable to use the common slip glaze on this clay, for the reason that the heat necessary to melt the glaze melts the ware also, and that he is compelled to glaze with common salt, which, however, is very satisfactory. The ware made from this clay shows to some extent a feature mentioned in connection with the Bird clay—a tendency to crack and warp in the dry house.

Sullenbarger clay.—The Sullenbarger clay bed is in the NE. ¼ sec. 20, T. 8 S., R. 15 W. The clay was used by Lafayette Glass in 1870. Nothing can be seen of the clay used, as the pit has long been filled up, but about 200 yards farther north, up the drain, 5 or 6 feet of rather dark gray clay outcrops, and this is reported to be similar to that used. It contains considerable sand, and although not very plastic has a soapy feel when rubbed in a damp state. The ware made from the Sullenbarger clay is thick and somewhat porous. A combination of this clay and the Welch clay was tried by Mr. Welch, who reports that the mixture worked more freely than the Welch clay alone and that there was less liability of cracking in drying or burning. This bed stands 260 feet above sea level. It is difficult to correlate this with any other bed in or near the Cheatham section. No outcrop of lignite was observed near by, nor was any reported in this vicinity. This clay probably comes above the Cheatham section, as the clay supplied came from an elevation of 280 feet. If these beds are to be correlated with any in the Cheatham section, it is evident that the character of the clay changes greatly in the distance between these localities.

Green's clay.—In the SW. ¼ NW. ¼ sec. 5, T. 8 S., R. 15 W., a clay outcrops at an elevation of 440 feet about 100 yards north of Mrs. M. C. Green's, in a small drain that runs west into Tunstle Creek. The bed is about 10 feet thick. The clay is light gray in color, is plastic, has little grit, and clings slightly to the tongue.

The refractoriness of this clay is not very high, yet it is by no means so low as that of the Cheatham clay, which has been very successfully used for pottery. The percentage of sand present is not large enough to be injurious. The analysis of the clay, as well as its physical appearance, indicates that it could be successfully worked into ware.

Tall's clay.—The clay at Mrs. Chloe Tall's place, in the N. ½ SW. ¼ sec. 4, T. 8 S., R. 15 W., at an elevation of 370 feet, is light grayish in color and very plastic and carries a small quantity of rather coarse grained grit. It includes small lighter or white particles.

This clay closely resembles the Bird clay, not only in physical appearance, but also in chemical composition, and will be found suitable for all uses for which the Bird clay is available. For practical purposes the quantity of this clay is unlimited.

Crowder's clay.—W. A. Crowder's clay is in the SE. ¼ NE. ¼ sec. 8, T. 7 S., R. 14 W. About 4 feet of the bed is exposed in the banks and bed of a small drain that flows into Miller Creek at an elevation of about 290 feet above sea level. The clay can be seen only in a weathered condition, but as such it is very tough, plastic, has little grit, and is one of the whitest clays examined.

In refractoriness this clay comes among those so much used for pottery about Benton, Ark., and just below the finest china clay from Cornwall, England, which it very much resembles in chemical composition. There can be no doubt that it is of the best quality.

The same bed crops out half a mile farther east, and search would undoubtedly reveal it in all the hollows in the neighborhood.

Clarks Creek clay.—In the SE. ¼ sec. 1, T. 8 S., R. 15 W., at an elevation of 280 feet, in the bank of a small drain running into Clarks Creek, there is an exposure of 4 or 5 feet of tough, plastic clay containing scarcely any grit. With the exception of about 1 foot in the middle of the bed, this clay is light gray in color. The middle layer is of lavender color and has a peculiar odor and a sharp, bitter taste.

This very interesting clay deserves a more extended examination than it has been possible to give it in this investigation. In several places within a mile or so of this occurrence, clay of apparently the same quality outcrops at the same elevation, so that there must be almost unlimited quantities of this clay.

Ramsey clay.—The Ramsey clay is exposed about one-half mile east of Ramsey post-office, in the NW. ¼ sec. 9, T. 10 S., R. 13 W. The clay crops out in a drain beside the Fordyce-Princeton road at an elevation of about 265 feet. The bed is exposed to a thickness of 10 feet. The clay is light bluish gray in color and very plastic, and the small amount of grit is very fine grained.

The proportion of alumina and silica in this clay is such that its refractoriness would be high were it not for the injurious amount of fluxes it contains, especially of magnesia, of which it contains more than any of the other clays analyzed. As it is, its refractoriness compares favorably with that of the Welch clay, and it may be used for all purposes for which the Welch clay is suitable. The quantity of this clay is apparently unlimited.

Wormac's clay.—W. L. Wormac's clay bed is in the NW. ¼ NW. ¼ sec. 29, T. 10 S., R. 14 W., at an elevation of 260 feet above sea level. It outcrops to a thickness of 4 feet at the foot of the west bank of Freeo Creek. A small drain empties into the creek at this place, and the clay crops out in this drain up to a spring which is 10 feet above and which probably emerges just above the clay. The clay also forms the bed of the creek for some distance south (downstream). This clay is of a dark slaty blue color, with a waxy luster when freshly exposed, but dries to a dull light drab.

The upper part of the bed, as exposed in the drain, is lighter in color. The clay in the creek bank breaks off in large, roughly rectangular blocks, from which small cubical pieces weather off, leaving a peculiar, angularly indented surface. The clay is plastic and the grit is very fine, being almost imperceptible.

In appearance this clay differs widely from the other clays of Dallas County, and on analysis shows a like difference in chemical composition. The degree of refractoriness is too low to permit its being used as a potter's clay, unless it be as an ingredient in other clays, and it is difficult to see how it could be beneficial as such.

The resemblance of this clay to some of the Tertiary clays that are used in refining oils is very marked, and its chemical composition is not far different from that of those clays.

Little Cypress Creek kaolin.—This bed crops out in the east bank of Little Cypress Creek, in the SW. ¼ NE. ¼ sec. 26, T. 7 S., R. 17 W., where the following section is exposed:

Section of Little Cypress Creek kaolin bank.

	Feet.
Drab sandy clay, overlain by soil, etc	7
Ferruginous shaly sandstone	½
Drab sandy clay as upper stratum	5
White sandy kaolin	6

The elevation of the base of the section is 320 feet.

The depth exposed does not represent the full thickness of the clay, which forms the bed of the stream and extends to an unknown depth below. It passes into yellow sandy clay 100 yards downstream. How far it extends upstream can not be told, for a few yards above the exposure the outcrop is covered with débris.

In J. E. Amis's well, about three-fourths of a mile farther southeast, a bed of white sandy clay and white sand, 20 feet or more in thickness, was struck at the same elevation. This may represent the kaolin bed. (See section of the well, p. 81.)

In appearance and texture this kaolin clay resembles the commercial scouring bricks, and it was with the thought of utilizing it for this purpose that the sample was collected. When rubbed between the fingers it has a lingering soapy feel, and it was washed and analyzed to test whether this indicated a constituency of kaolin.

In refractoriness this kaolin comes close below the best washed kaolin from Brandywine Summit, Pa., which is used in the manufacture of fine chinaware. In chemical composition, however, this Arkansas kaolin differs widely from the Pennsylvania variety in having more silica and less alumina and water. It is impossible to say what effect this difference in composition will have on the physical behavior of the clay in firing, but, the refractoriness being so nearly the same, the difference in composition will probably have no especially marked effect.

Kilmer kaolin.—A bed of kaolin outcrops on J. R. Kilmer's land in the SE. ¼ SE. ¼ sec. 10, T. 7 S., R. 17 W. A white clay outcrops in the bank of a drain at the elevation of 390 feet. Between 5 and 6 feet of the clay is exposed. It contains a great deal of rather coarse sand and in its natural condition is only slightly plastic. In the dry state the sand easily separates from the finely divided clay mass, which gives a very soapy feel when rubbed between the fingers, indicating the presence of kaolin.

The analysis shows a kaolin of a fair degree of refractoriness, the water content coming more nearly up to the accepted formula for kaolinite than that in the Little Cypress Creek kaolin. This kaolin will probably be available for the same purposes as the Little Cypress Creek kaolin.

OTHER CLAY BEDS.

The following notes on clay beds, which cover not only outcrops observed, but localities where clay was reported to occur, is inserted here on account of their possible value to prospectors.

In many cases the clay has been described as "sandy." Where this term has been used the sand is usually present in quantity sufficient to overcome the plasticity of the clay, or rather to lower the plasticity below the point at which it is available for ceramic purposes. One remedy for this fault consists in mixing with the sandy clay another clay of higher plasticity. Another remedy consists in washing out the excess of sand, a process that entails so much additional expense that it is impracticable except where the washed product is of a superior quality.

The exposures will be taken up in the order of the townships, beginning at the northeast corner of the county. The elevations are given in feet above mean tide level of the Gulf of Mexico. The elevation given for a well is that of the mouth; the elevation given for a natural section is that of the base.

Township 7 S., range 14 W.—Two feet of white plastic clay outcrops in a gully about 600 yards west of Ivy post-office, and is overlain by 6 or 8 feet of gravel. This is at the same elevation as the Crowder clay, which is less than half a mile distant (see p. 76), and is probably continuous with it. Elevation, 290 feet.

White plastic clay is reported on Gum Creek, in the SW. ¼ sec. 29.

Township 7 S., range 15 W.—In the SW. ¼ NW. ¼ sec. 2, in a gully just west of the Tulip-Sandy Springs road, there is an exposure of 15 feet of clay resting on white sand. The lower 7 or 8 feet is white plastic clay of apparently fair quality. It is possible that the white sand is a sandy kaolin similar to the Little Cypress Creek kaolin. Elevation, 360 feet. (See also p. 78.)

Nancy Jones's well, SW. ¼ sec. 2. Elevation, 390 feet.

Section in well of Nancy Jones.

	Feet.
Soil, gravel, and sand	8–10
White sandy clay	25
Dark clay	25

Lee Smith's well, NW. ¼ sec. 4. Elevation, 450 feet.

Section in well of Lee Smith.

	Feet.
Soil, gravel, and red sandy clay	20
White sand	5
Tough, dark, sandy clay	25

Outcrop of sandy gray clay, half a mile east of the above. Elevation, 380 feet.

Philip Phillips's well, SW. ¼ NW. ¼ sec. 5. Elevation, 500 feet.

Section in well of Philip Phillips.

	Feet.
Soil, gravel, and sandy clay	15
Sand and clay interstratified	20
White sandy clay	15

Chris. Lawrence's well, northeast corner SW. ¼ NE. ¼ sec. 30. The well was bored and afterward filled up. Reported by S. D. Green. Elevation, 490 feet.

Section in well of Chris. Lawrence.

	Feet.
Soil, gravel, and sand	25–30
Bluish clay (and bottom not reached)	125

This well must pass through the Bird clay, but as it is a bored well no distinction was made between the plastic clay and the sandy white clay, such as is found commonly in the upper part of this ridge.

Township 6 S., range 16 W.—Rice's gin well, SE. ¼ SW. ¼ sec. 36. Elevation, 510 feet.

Section in Rice's well.

	Feet.
Soil, gravel, and yellow sand	20
Bluish white clay, with interstratified beds of yellow sand	28

This is the typical white sandy clay referred to above. The sand constitutes 64.29 per cent of the whole mass.

G. A. Williams's well, NE. ¼ SW. ¼ sec. 36. Elevation, 510 feet.

Section in well of G. A. Williams.

	Feet.
Soil, gravel, and sand	15
Sandy pipe clay	60
Sand below.	

Township 7 S., range 16 W.—J. M. Holt's well, NE. ¼ SE. ¼ sec. 2. Elevation, 460 feet.

Section in well of J. M. Holt.

	Feet.
Soil and gravel	4
Sandy white pipe clay	40

J. S. Young's well, NE. ¼ SW. ¼ sec. 2. Elevation, 460 feet.

Section in well of J. S. Young.

	Feet.
Soil and gravel	4
Sandy white pipe clay	40
Lignite	1½
Dark-drab plastic clay	38

The lower 38 feet probably represents the Bird clay.

Mrs. E. A. Rice's place, NW. ¼ NE. ¼ sec. 15. White plastic clay nearly free from sand outcrops in the bed of a drain. Elevation, 415 feet.

In the Tulip-Arkadelphia road, about 1¼ miles east of O'Neill's mill, there is a bed of dark, putty-colored clay from 20 to 30 feet thick. This clay is very plastic, has little grit, and does not stick to the tongue. Elevation, 520 feet.

Potter's clay of excellent quality is said to have been taken from the creek bank below the old milldam at Willow post-office. The place is now covered with water. Elevation, 340 feet.

Potter's clay is reported in section 14, near the southwest corner, on a drain running into West Tulip Creek. Elevation, 300 feet.

It is also reported that a bed from which Bird used to take clay occurs in section 29, on a drain running into Cypress Creek.

Township 7 S., range 17 W.—J. E. Amis's well, NE. ¼ NW. ¼ sec. 36. Elevation, 360 feet.

Section in well of J. E. Amis.

	Feet.
Red sandy clay and gravel	15
Dark-drab plastic clay	5
White sandy clay and white sand	20

This probably reaches the kaolin that outcrops on Little Cypress Creek. (See p. 78.)

White plastic clay is reported in section 22, in the banks of a small drain, and in section 35, in the bank of Little Cypress Creek.

Township 8 S., range 15 W.—A white plastic clay outcrops in the bed of Canada Creek, just below the ford of the Ivy-Princeton road. Elevation, 250 feet.

A similar clay outcrops in the road a quarter of a mile south of the preceding and 30 feet higher in elevation.

On the Ivy-Princeton road, about three-fourths of a mile north of Princeton, there is an outcrop of very sandy white clay. Elevation, 260 feet.

In a gully beside the road in the NE. ¼ NE. ¼ sec. 21 there is a bed of bluish-white joint clay from 2 to 3 feet thick. This clay has little grit and does not cling to the tongue. It passes into sand to the north and into jointed and indurated sand of the same color 20 feet to the south. The joint cracks of the clay have been filled with sand carried by percolating waters. Elevation, 280 feet.

John C. Welch's well, in the NE. ¼ NW. ¼ sec. 19, passes through about 30 feet of white sand. It may be that this is a sandy kaolin similar to those described in the preceding pages. Elevation, 350 feet.

An outcrop of plastic gray clay occurs in the road about 400 yards east of Welch's pottery. The thickness of this bed was not apparent. Elevation, 440 feet.

There is said to be a fine bed of excellent potter's clay on a small stream north of Princeton, about 1 mile above a point where the stream is crossed by the Malvern road, 1 mile north of the town.

John C. Welch's clay bank, in sec. 17, T. 8 S., R. 15 W., is in a neighborhood that abounds in excellent clays. The beds occur also along both sides of Cypress Creek and of West Tulip and East Tulip creeks, near to the headwaters of those streams, winding in and out among the hills and cropping out in the bluffs and banks of streams. The covering of the beds varies greatly; where the overlying beds have been eroded away the covering is thin, but where they crop out in steep-sided hills it is generally thick. Where these clays have been dug they have been taken from beneath rather heavy coverings.

Mrs. Lantorn's well, sec. 17, 440 yards west of the northeast corner. Elevation, 310 feet.

Section in well of Mrs. Lantorn.

	Feet.
Soil and gravel	6
White pipe clay	10
White sand	2
White clay	27

A load of this clay was tried by Mr. Welch, who says that it works very well.

P. N. Lantorn's well, SE. ¼ NE. ¼ sec. 8. Elevation, 370 feet.

Section of well of P. N. Lantorn.

	Feet.
Soil and gravel	2
Hard bluish clay	58
Lignite	8

L. D. Lantorn's well, sec. 5, middle of the south side. Elevation, 480 feet.

Section of well of L. D. Lantorn.

	Feet.
Soil, gravel, and sand	10
White pipe clay	28

Mrs. M. C. Green's well, SE. ¼ NW. ¼ sec. 5. Elevation, 480 feet.

Section in well of M. C. Green.

	Feet.
Soil and gravel	8
White pipe clay	8
Bluish clay	27
Black "rock"	⅓
Lignite	3
Sandy bluish clay	30

A. Whitener's well, SE. ¼ NW. ¼ sec. 3. Elevation, 480 feet.

Section in well of A. Whitener.

	Feet.
Soil, gravel, and sand	15
White clay	1
Lignite	1
White plastic clay	14

This lowest clay outcrops in a gully 50 yards west of the house.

Township 8 S., range 17 W.—D. Ratliffe's well, SE. ¼ SE. ¼ sec. 2. Elevation, 290 feet.

Section in well of T. Ratliffe.

	Feet.
Soil and red clay	4
White plastic clay	30
Dark plastic clay, with ferruginous sandstone particles	10

There are scattering leaf impressions in both the light and the dark clays.

Bernard Dellamar's place, SW. ¼ NW. ¼ sec. 14. An exposure of 12 feet of dark bluish drab clay. This clay is plastic and has little grit. Elevation, 310 feet.

Outcrop of 15 feet of light-blue plastic clay beside the road in the NW. ¼ sec. 15. This clay weathers very much like the olive-green Tertiary marl. It contains somewhat more grit than the clay that is most used for ware in this country. Elevation, 320 feet.

J. R. Porterfield's well, SE. ¼ NE. ¼ sec. 17. Elevation, 350 feet.

Section of well of J. R. Porterfield.

	Feet.
Soil and gravel	17
Sand	1
Dark, soft, plastic clay, with lignite flakes and nodules of iron pyrites.	16

Potter's clay is reported near the center of sec. 34; also near the northeast corner of sec. 27 and in the SE. ¼ of sec. 35.

A well in the NW. ¼ NW. ¼ sec. 36 passes through 75 feet of sand with lumps of plastic clay and ends in white sandy clay similar to that overlying the lignite bed in this region. Elevation, 280 feet. These lumps of clay are at many places embedded in the sandy strata, and have been reported in several wells.

Township 9 S., range 14 W.—Pottery clay is reported in the SW. ¼ SE. ¼ sec. 32, and in SE. ¼ SE. ¼ sec. 30.

Township 9 S., range 15 W.—From 2 to 4 feet of bluish-white plastic clay outcrops in a gully beside the road in the SE. ¼ SE. ¼ sec. 34.

In the bank of Hays Creek, SE. ¼ NW. ¼ sec. 5, there is an outcrop of about 15 feet of grayish joint clay with considerable sand. Elevation, 220 feet.

Potter's clay is reported in the NW. ¼ SW. ¼ sec. 18; also on Sand Creek, in the NW. ¼ sec. 20.

Potter's clay is reported on the Bowers place, near the center of sec. 22.

Clay which was pronounced good is said to occur in the SW. ¼ SW. ¼ sec. 6.

Grayish-green potter's clay, 10 to 12 feet thick, outcrops on the Princeton-Dalark road, in sec. 11.

Township 9 S., range 16 W.—C. C. Williams's well, NE. ¼ NE. ¼ sec. 18. Elevation, 290 feet.

Section in C. C. Williams's well.

	Feet.
Soil and gravel	8
White pipe clay	20

Township 9 S., range 17 W.—Frank Russell's well, SW. ¼ sec. 1; 15 feet of plastic clay in bottom. Elevation, 290 feet. The same clay outcrops in a spring a few yards north of the well.

Where the Fordyce-Princeton road ascends the hill at Dallas Stell's ("Stony Point"), just north of Cooks Creek, in the S. ½ sec. 18, T. 10 S., R. 13 W., halfway up the hill, is a 10-foot bed of clay which may prove valuable for pottery, though the best of the clay may be only that near the surface, which is most affected by weathering. It is possible that it is thicker than 10 feet, for the limits of the bed are not well defined.

A well dug about 1,500 feet north of Dallas Stell's house penetrates lead-colored sands with leaf impressions, and it is possible that the clay on the hillside south of the house may be the weathered edge of this sandy stratum.

Through the region traversed by the Fordyce-Princeton road many of the surface clays are well adapted for pottery, but they all contain some pebbles and would need to be screened or passed through a machine to remove these.

Many exposures of stratified beds of pottery clay have been observed along the road south of Princeton, but the region is thinly settled and it is not possible to give the land divisions on which they were found. They vary greatly in thickness, though it is probable that many of the beds which appear to be but 2 or 3 feet thick are much thicker, and that only small portions of them are exposed.

On the road leading from Princeton to Fordyce, about 1½ miles south of the point where the Fordyce road leaves the Camden road, a 10- or 12-foot bed of pottery clay is exposed in a gully beside the road.

The road from Tulip to Dalark passes over several beds of pottery clay. They crop out, among other places, in secs. 15 and 16 of T. 8 S., R. 17 W., on the lands of George Elders, about 4 miles east of Dalark, where they are overlain by red clayey sands.

A light-colored pottery clay outcrops in the gully east of the road in the NE. ¼ NE. ¼ sec. 20.

Township 10 S., range 14 W.—White plastic clay is reported in the NW. ¼ NE. ¼ sec. 5 and the NW. ¼ NW. ¼ sec. 7.

A. B. Smith's well, SE. ¼ sec. 8. Elevation, 265 feet.

Section in well of A. B. Smith.

	Feet.
Soil, red clay and gravel	12
Bluish joint clay	40
Red sandy clay	8

This clay evidently passes into sand, for a well at the same elevation 100 feet away shows:

Section in well in SE. ¼ sec. 8, T. 10 S., R. 14 W.

	Feet.
Soil and gravel	12
White fine-grained sand	33

Potter's clay occurs in the SE. ¼ sec. 8. Ten feet is exposed in the road and in the banks of a stream that flows into Freeo Creek. Elevation, 250 feet.

Potter's clay outcrops in the Little-Bay Princeton road in the SW. ¼ sec. 16. Elevation, 265 feet.

Smith place, SE. ¼ NW. ¼ sec. 17. Two or three feet of white plastic clay is exposed in the bank and bed of Freeo Creek, immediately above the ford. Elevation, 230 feet.

R. H. Barner's well, NE. ¼ NE. ¼ sec. 20. Elevation, 275 feet.

Section in R. H. Barner's well.

	Feet.
Red clay and sand	7
Blue joint clay, sandy toward bottom	34

Between 10 and 15 feet of grayish pottery clay outcrops in the road in the NW. ¼ sec. 34. Elevation, 270 feet.

Township 10 S., range 15 W.—In a gully beside the road, north of a church in the NW. ¼ sec. 2, is an exposure of 8 to 10 feet of bluish-white plastic clay. Elevation, 235 feet.

J. T. Shankle's well, SW. ¼ NW. ¼ sec. 7. Elevation, 300 feet.

Section in well of J. T. Shankle.

	Feet.
Red sand and clay	20
White pipe clay	10
Dark lumpy clay	10

A bored well at the same elevation showed 22 feet of the dark clay and stopped in lignite. The dark clay contains a few leaves.

J. W. Richardson's place, SE. ¼ SE. ¼ sec. 9. Ten feet of gray plastic clay outcrops beside the road. Elevation, 240 feet.

Potter's clay 15 feet thick outcrops in a gully in the SE. ¼ SW. ¼ sec. 16, and is underlain by 10 to 20 feet of white sand. Elevation, 260 feet.

Potter's clay is reported in a well at the gin in the NW. ¼ SW. ¼ sec. 18.

Pottery clay outcrops in the road in the NW. ¼ sec. 21. Elevation, 260 feet.

Potter's clay is reported in the NW. ¼ sec. 22.

Township 10 S., range 16 W.—W. M. Walsh's well, NE. ¼ NW. ¼ sec. 1. Elevation, 265 feet.

Section in well of W. M. Walsh.

	Feet.
Red clay and sand	8
Black clay with leaf impressions	10
Yellow sand and clay	45
White plastic clay	4

Well stopped in the last stratum without passing through it.

On Peterson's place, NE. ¼ SW. ¼ sec. 12, a foot of light-colored clay with some grit is exposed in a drain. Elevation, 230 feet.

James Goodgame's well, NW. ¼ NE. ¼ sec. 13. Elevation, 240 feet.

Section in well of James Goodgame.

	Feet.
Soil	4
Pipe clay	17

R. E. Hogg's well, SW. ¼ SE. ¼ sec. 13. Elevation, 310 feet.

Section in well of R. E. Hogg.

	Feet.
Soil and gravel	10
Potter's clay	2-3
Sand below.	

CONCLUSIONS.

The geologic structure of the region and the known outcrops of potter's clay lead to the conclusion that such clays exist in great abundance and of excellent quality in Dallas County. Their widespread distribution on both sides of East Cypress and Cooks creeks and of West and East Tulip creeks has already been mentioned. In addition to the places at which good clays are already known, there is no doubt that they will also be found on the west side of Moro Creek and on the higher lands skirting the west side of Saline River in Dallas County.

ANALYSES OF CLAYS.

Analyses of clays in Dallas County are given in the following table:

Analyses of Dallas County clays.

Clays analyzed.[a]	Silica.	Alumina.	Ferric oxide.	Titanic oxide.	Lime.	Magnesia.	Soda.	Potash.	Loss on ignition.	Sand in air-dried clay.
Cheatham clay	72.82	13.72	1.267	2.54	0.63	0.75	1.08	0.96	5.76	50.30
Bird clay	66.42	21.19	1.956	1.02	1.13	.82	1.26	....	7.76	37.28
Welch clay	71.27	16.86	2.378	1.75	.73	.77	.46	.44	6.54	30.50
Green's clay	68.03	17.19	3.589	1.49	.81	1.00	.54	1.00	6.31	35.80
Tall's clay	62.343	20.631	4.082	1.556	.173	.668	.325	.729	9.339	16.73
Crowder clay	66.336	18.966	2.008	1.869	.256	.225	.800	.379	8.130	17.23
Clarks Creek clay	50.653	25.450	6.481	2.591	.167	.604	.242	.742	13.100	3.46
Ramsey clay	60.700	21.567	5.000	.447	.469	1.583	.297	1.526	8.608	15.25
Wormac's clay	64.734	16.569	3.796	1.234	.837	1.535	1.395	1.685	7.334	25.14
Little Cypress Creek kaolin	62.166	26.096	.341	1.302	.051	Trace.	.252	.364	9.067	67.94
Kilmer kaolin	52.269	32.207	1.781	1.505	.086	.028	.341	.271	11.170	38.57

[a] The exact locations of the clays are stated in the preceding pages.

Of the preceding eleven analyses the first four were made by W. C. Riley and the remaining seven by L. R. Lenox. It will be noticed that the clays analyzed by Doctor Riley show a much higher percentage of sand than those analyzed by Professor Lenox. The determination of the percentage of sand is at best only approximate and is a matter of individual judgment, and this accounts for the different percentages found. In two clays, which have to all appearances an equal amount of sand, the percentage of sand in the one as determined by Doctor Riley is about twice as great as the percentage in the other as determined by Professor Lenox. In comparing the sand contents of the clays this should be borne in mind.

Each of the clays analyzed contains a considerable amount of titanic acid and smaller quantities of sulphuric and phosphoric acids. Neither of these substances is taken into consideration in the formula devised by Bischof for calculating the refractoriness of clays, so that in determining the refractoriness of the clays analyzed these constituents have been disregarded. It is highly probable, however, that they exert some influence on the fusing point of clays.

Several of the clays showing the largest percentages of titanic acid were washed and their coarser and heavier parts were examined under a microscope. Owing to the fragmentary condition of the particles it was not possible to identify any of them except the quartz.

CLAY INDUSTRY.

At present no plants are reported as engaged in the manufacture of clay products in Dallas County. The pottery industry of the county has been mainly confined to the operations of the Bird brothers and their apprentices. The first pottery was established by them, and the last active pottery in the county was owned and operated by John C. Welch, who learned the potter's trade under William Bird.

The first pottery was set up in 1843 by two of the brothers, Joseph and Nathaniel Bird. In 1844 James Bird, another brother, erected a pottery just over the county line, in Grant County, in the SE. ¼ SE. ¼ sec. 23, T. 6 S., R. 16 W. He had burned but a few kilns when he sold out, and the business was discontinued. He used clay from a bed close by the old shop.

William Bird started his first pottery in 1843, in the SW. ¼ NW. ¼ sec. 7, T. 7 S., R. 15 W. His clay came from the Butler bed. He continued steadily at work here until 1851 or 1852, when he moved his shop to the site now occupied by John C. Welch's pottery, in the NW. ¼ SW. ¼ sec. 17, T. 8 S., R. 15 W. He operated this pottery until 1861, when he sold out to Welch. While running here he used clay from the Butler bed, and later from the Cheatham beds also. Bird started another pottery at the close of the war on what is known as the Bird place, in the SW. ¼ NW. ¼ sec. 6, T. 7 S., R. 15 W. He continued here until about 1881, when he left the State. He afterward returned and followed his trade in Malvern. While at the Bird place he used clay from the Butler bed; also from the Bird bed, on the Bird place, and from Gum Bottoms. Bird has the reputation among the older inhabitants of the county of making very fine, durable ware.

John C. Welch, as before noted, learned the trade under William Bird, and in 1861 bought him out and continued the business at the same place. The capital invested, exclusive of that for location, was about $150. The kiln had a capacity of 1,500 gallons. Two wheels were run and the average annual output was 10,000 or 15,000 gallons. The product was in the form of jugs, jars, churns, and crocks, which found a market in neighboring towns—Pine Bluff, Camden, Warren, Monticello, Eldorado, Magnolia, and other places. Mr. Welch at first used clay from the Cheatham beds, but later found and worked the Welch bed. His ware was hard, close-bodied, and thin.

Nathaniel Culberson worked awhile with Welch, and between 1858 and 1865 ran a pottery near the middle of sec. 24, T. 8 S., R. 15 W. He used clay from the Cheatham beds. Fragments from the old kiln show a rather thick, porous ware.

In 1859 or 1860 a foreigner named Etl established a pottery about three-fourths of a mile north of the preceding and operated it for about three years. Besides ordinary crockery he made flower pots with vines and flowers in relief on the sides. He used clay from the Cheatham beds.

In 1870 Lafayette Glass, after learning the trade under Welch, set up a pottery in the NE. ¼ SE. ¼ sec. 29, T. 8 S., R. 15 W. He operated here for a year and then removed to Benton and became the pioneer potter of that place. While in Dallas County he used clay from the Sullenbarger bed.

Between 1874 and 1876 E. A. Munn, a brother-in-law of Welch, ran a pottery in the NE. ¼ SE. ¼ sec. 12, T. 8 S., R. 16 W. He left there and established a pottery at Malvern. He used clay from the Welch bed. Fragments about the old kiln show a fine, hard, and close-bodied ware.

DREW COUNTY.

GENERAL GEOLOGY.

The surface soils of Drew County consist either of disintegrated Tertiary (Eocene) rocks, which underlie the whole county, or of a thin coating of gravel of later age on the Tertiary beds. The flood plains of some of the streams are of recent alluvial origin, while those of others are made of older clays. Nearly all the lands east of Hurricane Creek are alluvial. Excellent brick clays are abundant about Monticello, though some of the surface clays contain a few pebbles, and others contain iron nodules. In the western part of the town of Monticello about 30 feet of purple and mottled Tertiary clay are exposed in gullies and in the railway cut. The purple clays crack in drying and, in their present condition, are not available for brick-making. These beds are exposed in places for 2 miles west of the town of Monticello.

A well bored by Emil Boechardt at Monticello in 1889, on the southwest corner of sec. 35, T. 12 S., R. 7 W., passed through the following strata. as reported by Mr. Boechardt:

Section in well of Emil Boechardt.

	Ft.	In.
1. Loam		4
2. Red clay	5	6
3. Pipe clay and sand	15	
4. Dark clay with shells	50	
5. Sandstone		6
6. Dark clay with shells	88	6
	159	4

A sample of clay No. 6 of this section was examined by the Arkansas Geological Survey. It is a dark, fine clay with a little mica and a few fragile fossil shells of Tertiary age. It does not crack on drying, and if the beds are accessible and could be found without shells it would make a good potter's clay and would be available for the manufacture of good fire bricks. It is probable that other Tertiary clays that underlie Drew County might, by washing, be made available for the manufacture of pottery.

At Cornish Ferry, on Saline River, a section of the Tertiary beds is exposed, having at the base a dark lignitic clay that resembles some of the pottery clays of Saline County.

CLAY INDUSTRY.

In the town of Monticello the Drew Brick Company and a plant operated by J. H. Blythe are engaged in the manufacture of common building bricks.

FAULKNER COUNTY.

GENERAL GEOLOGY.

The geology of Faulkner County is merely a repetition on a somewhat larger scale of that of the western part of White County. The rocks have been thrown into great folds and then worn away, but the folding has been, on the whole, so simple and the alternation of the sandstones and shales has been so regular, that the geologic structure of the county is easily interpreted. When this structure is understood the distribution of the clays and clay shales in the county will be readily comprehended.

The rocks of this region belong to what are commonly known as the "Barren Coal Measures." They are sandstones and shales, across which run occasional veins of quartz, and on the upturned edges of which there are patches of bog iron deposited by chalybeate springs. Locally the sandstones and shales are somewhat calcareous, but these calcareous places are only thin bands or small patches and are of little or no importance except that some of them contain fossils.

The rocks of the county are all sedimentary, having been deposited originally in horizontal layers in water. After their deposition these sediments were consolidated by the pressure of thick beds that were deposited on top of them. In the course of time they were subjected to horizontal pressure from the south and thrown into a series of parallel folds, and, rising above the water, they formed dry land. After this elevation they were acted upon by weathering and eroding agencies, the former breaking up the rocks (for these sediments, originally sand and mud, were already hardened by long pressure to sandstone and shale) and the latter washing the fine material away. But as rocks are not all equally soluble or equally acted upon by decomposing and weathering agencies, and as they are not all transported with the same facility after disintegration, some of these rocks in Faulkner County have been removed much more rapidly than others. Thus rocks which long resist decay and removal—that is, the sandstones—stand out now as hills and ridges, while eroding agencies have scored valleys in the softer and more easily affected rocks—that is, the shales. As the rocks of this region are alternate sandstones and shales, the topographic result of this condition and action is a series of parallel valleys and ridges, running, as a rule, east and west across the county.

As a rule the axes of these rock folds are not horizontal but are a little lower at one end than at the other. From this dipping of the folds it results that the ridges, instead of being everywhere straight, curve around and cross the lower ends of the axes of the folds. This will be understood by reference to the accompanying diagram (fig. 7).

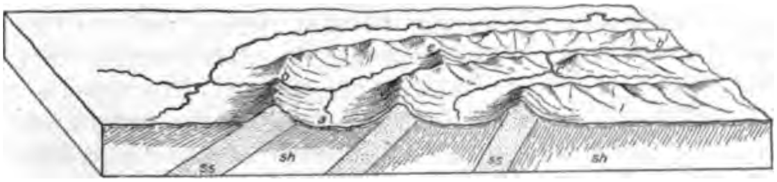

FIG. 7.—Diagram showing relations of structure to topographic relief in Faulkner County. *sh*, Shale; *ss*, sandstone; *aeb*, valley; *c*. *o*, stream piracy; *e*, watershed.

It will be understood from this also that the valley *aeb* is one and the same geologically, although it may be divided at *e* by a watershed, or the ridge may be broken at *o* and *c*. It should also be noted that the shales that dip westward at *a* dip northward at *e*, and the same bed would dip southward on the south side of the axis of the fold.

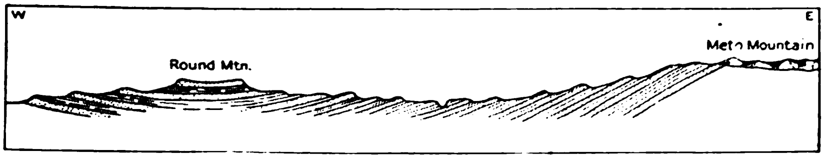

FIG. 8.—East-west section through Round Mountain and Meto Mountains, Faulkner County.

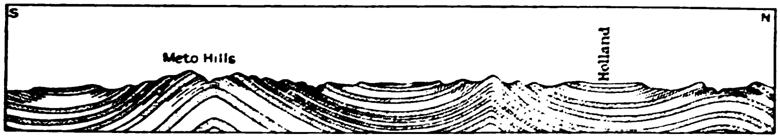

FIG. 9.—North-south section through Meto Hills.

Fig. 8 is an east-west section along the summit of Meto Mountain (a group of parallel ridges about 5 miles wide lying just north of Faulkner Gap) and across the summit of Round Mountain to Arkansas River.

A north-south section across the Meto Hills to a point about 3 miles north of the town of Holland is given in Fig. 9.

These details are sufficient to give a pretty clear idea of the geology of Faulkner County with reference to the occurrence of the clays and clay shales. The shales form the valleys of the region; the sandstones form the ridges. The shales are seldom seen at the surface, being covered usually by residuary material of one or another kind. At many places, especially in the lower valleys or "slashes," the surface soil is a "buckshot clay."[a]

About the bases of the sandstone ridges the débris from the hillsides—blocks of sandstone and sandy red clays—cover the outcrops. The shales are almost invariably found in digging wells, so that the people have an idea that the shale or "slate," as they generally call it, lies close to the surface all over the county. This appears to be the case, because the wells are usually dug in the valleys and the valleys are carved in the shales. This will be understood from the accompanying figure, which shows the geology of the region about Conway with relation to the shales, the decayed shales, and the soil of the valley to the sandstone on Cadron Ridge, a short distance north of the town.

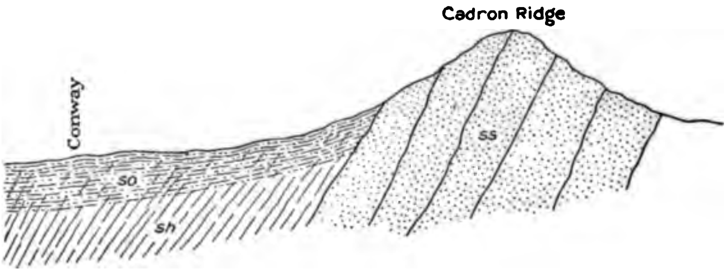

FIG. 10.—Section showing the relations of the shales of the valley to the loam and soil about Conway. *so*, Soil; *sh*, shale; *ss*, sandstone.

CLAY DEPOSITS.

The clays and clay shales of Faulkner County are of four kinds—(1) clay shales; (2) limonitic buckshot clays; (3) leached clays along the bayous and in the slashes; (4) alluvial and sandy chocolate clays skirting the bottoms of Arkansas River and in some places extending far up its affluents from this county, such as the Cadron.

CLAY SHALES.

With the preceding explanation of the geologic structure the distribution of the clay shales may be readily understood. They lie in the valleys everywhere in the county. Of course there are lowlands, like the alluvial plains of Arkansas River, made up to a considerable depth of river silt, clay No. 4 of the above list, sand, and gravel, to which this statement is not intended to apply. The alluvial materials that have filled the valleys of some of the other streams have also buried the shales to a considerable depth. These are not the places, however, in which one would expect to find the clay shales accessible for practical purposes. Indeed, while the valleys have shales of great thickness, the rocks are usually at too low an elevation to permit advantageous exploitation, on account of the expense of lifting the material from shafts or other openings and of draining these openings. Crude material to be cheap must be easily accessible and must therefore be sought on high ground, where the locality facilitates exploitation and avoids the necessity of draining the pits. There are several shale hills and ridges in the county where these conditions are favorable, and if one observes the geologic section north and south across the county it will be seen that these places are most likely to occur on the axes of the synclinal folds. One of these hills is known as Round Mountain, and is located in secs. 11 and 14, T. 5 N., R. 12 W., about on the axis of the Conway syncline. This little mountain stands about 250 feet above the general level of Cypress Valley and is in every respect similar to one having the same name in White County, which is located, like this one, on the axis of the Conway syncline. The rocks here are nearly horizontal, dipping gently to the south beneath the mountain, which is capped by a bed of sandstone that has preserved what remains of it from complete destruction. The total area covered by this mountain is about one-half a square mile.

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[a] For the discussion of the buckshot clays see p. 28.

Samples of the shale from this mountain have not been analyzed, but samples from the same beds in Round Mountain of White County have been analyzed and it is probable that they have the same or approximately the same composition. These analyses are given on page 224.

No coal has been found in the Faulkner County mountain, but the existence of a 2-foot bed of coal in the White County mountain warrants the supposition that there may be a similar bed in this one also.

Just west of Round Mountain is another though somewhat smaller hill, which has no local name. This hill has the same geologic structure as Round Mountain and is composed of the same kinds of rocks, which lie in the same position. It stands in sections 15 and 16 of the same township and covers an area of about 160 acres.

The other synclines in which the argillaceous shales abound are the Holland syncline, the Greenbriar syncline, and the Cato syncline. The shales of the Holland syncline are exposed in the Conway-Greenbriar road in sec. 13, T. 6 N., R. 14 W., where the road crosses East Cadron Creek. The body of the ridge just north of the creek at this place is of clay shale, and the whole is capped by sandstone. The ridge extends a mile to the west of the East Cadron bridge, but to the east it bends gently toward the south to sec. 15, T. 6 N., R. 12 W., where it curves abruptly northward, passes to the east and north of the village of Holland, and, bending upon itself, passes westward by Linden post-office.

This syncline is topographically highest at its western end, where the hills stand about 150 feet above the valley, and it sinks gradually to the east. The shales forming the body of this elevated syncline are well above water level, and as they are nearly flat there would be no difficulty in mining them. Their distance from the railway, however, will doubtless prevent their being utilized for the present.

Horseshoe Mountain, near Greenbriar, stands on the axis of the Greenbriar syncline. This mountain, like the other synclinal ridges, is composed mainly of argillaceous shale and, like them, is capped with a protecting bed of sandstone. It rises abruptly from the Greenbriar Valley, above which its summit stands about 300 feet, but sinks to a level about 100 feet above the Cadron. These shales, while available in so far as their composition, abundance, and geologic and topographic disposition are concerned, are too far from railway transportation to be of immediate use for manufacturing purposes.

Frenchman Mountain marks the axis of the Cato syncline. It is about 250 feet high at its east end, about a quarter of a mile west of the town of Cato, but becomes lower toward the west. The axis of this syncline dips toward the west, so that the mountains open westward, and the axis crosses the St. Louis, Iron Mountain and Southern Railway near Mayflower station.

The heavy beds of argillaceous shale forming the base of Frenchman Mountain are protected by the usual sandstone bed. This locality is several miles from the railroad.

The so-called Round Mountain group of ridges, lying between Preston station and Arkansas River, is made up of alternate beds of sandstones and shales that set one in the other like a nest of saucers. Many of these basic shales are adapted to the manufacture of pipes and paving bricks, but they have never been utilized. The less basic beds are available for the manufacture of refractory goods. They all occur in the greatest abundance, well located topographically, of good quality, and convenient to the St. Louis, Iron Mountain and Southern Railway.

Clays derived directly from shales by decomposition are common over much of Faulkner County, but as a rule they are so concealed and so irregular in distribution that but little can be said of them. They are to be sought on the upturned edges of the clay shales where these rocks have broken down under disintegrating influences, and as the sandstones usually form the hills and ridges and the shales the valleys, these clays are to be looked for chiefly in the valleys, between the sandstone ridges. Such clays are often spoken of by the people as "rotten slate." They are abundant at the bases of some hills of shale where the shale talus has been broken up by long exposure to percolating waters.

Some of these clays are available for making rough pottery, such as jugs, crocks, and churns, or for making vitrified bricks or sewer pipes. The deposits are generally too small, however, to be of much importance.

LIMONITIC BUCKSHOT CLAYS.

The ordinary buckshot clay—that is, the clay containing small nodules or concretions of iron—occurs over half of Faulkner County. It is most abundant in the valleys and over the flat portions of the uplands of the county, and is least abundant on the crests of sharp ridges and in the alluvial bottoms of the Arkansas. Where it is near the sluggish bayous, and is overflowed for many days and even weeks each year, waters charged with organic matter have leached the iron from its upper portion, leaving it in places a clean, white potter's clay. This same process, operating on a minor scale, has produced the yellowish or ash-colored loam that forms the surface soil over a large portion of the county. From this loam most of the bricks of Faulkner County are made.

Beneath this more earthy surface there is generally an irregular bed or band of nodules of limonite iron that renders the clay difficult to manipulate, especially when the bricks are handmade, and produces the dark chocolate and spotted color so common in bricks from such soils.

The limonitic buckshot clay is so widely distributed in Faulkner County that it may be said to form the agricultural soil of three-fourths of the county. It is doubtless thickest in the valleys, in nearly all of which it covers large areas. It is in the "slashes," however, or wherever the ground is flat enough to prevent quick drainage, that it occurs in its most characteristic forms.

Throughout the Cypress Valley, from the Arkansas bottoms to the eastern border of the county, the buckshot limonitic clays are concealed only by the thin surface soil, which is in reality but a part of the blanket of clay soil that covers the whole region. The same is true of all the other valleys of the county, but especially of those in which there is slash land, or over which the drainage is sluggish. About Conway, Greenbriar, Holland, Enolia, and Amsteadville these clays are abundant, and are everywhere available for making such bricks as are usually made of the limonitic clays.

LEACHED CLAYS.

The leached clays are but one phase of the buckshot clays, being the upper soils from which the iron has been removed by acidulated waters. As a rule the longer the water stands on the ground the more thoroughly is the iron leached from the soil, and it is by this process that the leached lead-colored clays are formed. Such clays are therefore most common along the sluggish streams that readily overflow their banks and spread out over wide, marshy bottoms, such as Palarm Bayou, East Cadron Creek, and Bayou Meto. And it is over the flood plains of these streams that the leached clays are most abundant; not, however, in the valleys only, but wherever the conditions for their formation are favorable.

The leached clays are available for the manufacture of the common grades of pottery, such as jugs, crocks, jars, and milk pans, but as their exploitation is not so easy as that of the Tertiary potter's clay of the southwestern counties of the State, they can scarcely compete with those clays. and can therefore be of slight and local importance.

CHOCOLATE CLAYS.

The chocolate-colored clays in some places form what are known as the "rich buckshot lands"[a] adjoining the river bottoms. They are usually too sandy to be useful for manufacturing purposes. In places they are very "fat." They are not everywhere of chocolate color, for wherever they contain much organic matter they have become black from the mixture of the organic matter with the lime with which this clay is at most places freely charged. Some of the richest agricultural lands of the State are on these chocolate clays. They are not known to have any value for manufacturing purposes.

CLAY INDUSTRY.

The Cypress Valley region about Conway[b] is covered by a yellowish clay, mottled here and there with light-gray patches. These gray patches are generally of small area and not very thick. In texture the gray clay resembles the yellow, although it has somewhat different qualities when manufactured. The upper portion of the yellow clay, from which the bricks are usually made, is of a light-yellow color, is generally about 2 feet in thickness, and is comparatively free from iron nodules. The lower division, from 24 to 30 inches thick, is of much darker color, and contains a great quantity of iron nodules ranging in size from that of a pin head to that of a walnut. This lower clay is not much used for brickmaking. The bricks made from it are stronger, harder, and more durable than those made from the upper clay, but they do not look so well.

The clays just mentioned are underlain everywhere throughout this district by a black argillaceous shale, which is more or less fractured near the surface, becoming harder and more compact as they are penetrated. The upper layers of this shale at some places break into kidney-shaped pieces, which shell off concentrically.

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[a] Not to be confused with the limonitic buckshot clays

[b] The notes on the brick industry at Conway were prepared principally by William Kennedy.

A well at John McCullough's old brickyard, in the NE. ¼ NE. ¼ sec. 1, T. 5 N., R. 14 W., gives the following section:

Section at John McCullough's old brickyard.

	Feet.
Light-yellow clay used for bricks	2
Dark-yellowish clay, brown below, and containing iron nodules	2
Broken black shale	3
Hard black shale at bottom of well.	

On the northeast corner of block 42 of the town of Conway, about 1 mile southwest of McCullough's old yard, in a well about 200 yards east of Mr. Firestone's brickyard, the shales appear at a depth of a little over 3 feet. In Firestone's pits the clay used does not exceed 2 feet in thickness. This clay is darker than that formerly used by McCullough and contains more iron nodules.

The bricks are gray in color, and where the two clay beds have been mixed the bricks are spotted. In the arch they have a tendency to melt at the ends.

Secs. 18 and 19 and 7 and 8, T. 4 N., R. 14 W.; secs. 10, 11, 12, 13, 14, 15, 22, 23, 24, 25, and 26, T. 5 N., R. 14 W.; and secs. 6, 7, 18, 19, 30, and 36, T. 5 N., R. 13 W., are covered by yellow clay similar to that around Conway.

Mr. Firestone made common bricks by hand until 1902, when he installed a machine run by steam. He now makes a stiff-mud end-cut brick. The clay is tempered and molded in a No. 7 special plunger machine, dried in the open air, and burned in clamp kilns. It requires about seven days for burning. Two kilns are in use, each of which has a capacity of 200,000 bricks. Wood is used for fuel. Daily output, 16,000 bricks. Size of bricks, 8¾ by 4¼ by 2½ inches.

FRANKLIN COUNTY.

GENERAL GEOLOGY.

In the extreme northern part of Franklin County, along Mulberry River and the tributaries entering that stream from the north, rocks are exposed that underlie the whole series of the coal-bearing rocks. These are the lowest and oldest rocks of Franklin County, and consist in part of beds of limestone. So far as is now known no clays or clay shales are associated with these old limestones. South of these exposures along Mulberry River the rocks of all the rest of the county are newer and are higher up in the geologic column and belong to the coal-bearing rocks or the series known as the "Coal Measures"—a series rich in clay shales and fire clays.

The rocks at and near the surface over most of the county are geologically somewhat higher than the coal beds found at the Ouita, Spadra, and Coal Hill mines. The Spadra shale, with the accompanying coal, extends westward from Allister about 7 miles into Franklin County. The Spadra shale covers all the area within T. 9 N., R. 26 W., lying south of the section line between secs. 13 and 24, and extends still farther south, to Arkansas River. They likewise include secs. 25 and 36, T. 9 N., R. 27 W. Over a large part of this area clay shales are associated with the coal, and much of this deposit promises to be available for the manufacture of fire-clay products and also for sewer pipe and paving brick.

Both north and south of the area here mentioned, as well as west of it, the rocks are higher in the geologic column. They consist, however, of shales and sandstones that closely resemble those lower down, in the coal-producing rocks.

The following characteristic section, exposed on the east bluff of Arkansas River by the railroad about a mile southeast of the town of Ozark, shows the kinds and thickness of most of the rocks of Franklin County:

Section near Ozark.

	Feet.
Sandstone	50
Shale	90
Sandstone	15
Shale	70
Sandstone	10
Shale	75
Sandstone	50

In the southern part of Franklin County there is a series of rocks that stands higher in the geologic column than those included in this Ozark section. These higher rocks belong to the group which has been called in Arkansas the "Poteau." They cover all of Franklin County south of Short Mountain Creek and south of the Vesta coal bank in T. 8 N., R. 29 W. These higher rocks are likewise exposed over a comparatively small area northeast of Ozark. They form what is called the Philpott coal basin, which extends from Moomaw's coal bank eastward (and a little northward) for about 16 miles. These uppermost formations include many beds of shale and also the coal beds of the upper productive part of the coal-bearing rocks and the fire clays associated with the coal beds.

CLAY DEPOSITS.

CLAY SHALES.

Unfortunately only one analysis has been made of a sample of clay from Franklin County, but it seems safe to infer that the analyses of the shales of White, Pulaski, Johnson, and Sebastian counties give a good idea of the character of the clays and clay shales of Franklin County.

It seems probable that the fire clays and the clay shales of Franklin County that show rather high refractoriness are capable of being extensively utilized. The following three exposures along the railroad near Ozark were noted by Mr. Kennedy:

In the SE. ¼ SW. ¼ sec. 12, T. 10 N., R. 26 W., a bed of fire clay 4 feet thick underlies 2 inches of broken coal and overlies the black shales exposed in the water courses of this district. About 2 miles east of Ozark, in the NW. ¼ sec. 8, T. 9 N., R. 26 W., in a cut on the track of the St. Louis, Iron Mountain and Southern Railway, there is an outcrop of fire clay 20 inches thick lying immediately beneath 3 inches of coal. The section exposed is as follows:

Section in railroad cut 2 miles east of Ozark.

	Ft.	in.
Flaggy sandstones	4	
Coal		3
Fire clay	1	8
Arenaceous shales and thin sandstone at the base.		

Analysis of clay from railroad cut 2 miles east of Ozark.

[Brackett & Smith, analysts.]

Silica (SiO_2)	62.92
Alumina (Al_2O_3)	23.60
Ferric oxide (Fe_2O_3)	3.17
Lime (CaO)	.23
Magnesia (MgO)	.57
Potash (K_2O) Soda (Na_2O) } (by difference)	3.77
Loss on ignition (H_2O)	6.74
	100.00
Water at 110°-115° C	2.65

On the same railroad at the end of an embankment in the NE. ¼ NE. ¼ sec. 7, T. 9 N., R. 26 W., a small stream cuts through a bed of blue and yellow shales 8 feet thick. These shales are readily disintegrated by atmospheric action and are almost free from sand. They are overlain by a bed of sandstone about 1 foot thick.

In the SE. ¼ SE. ¼ sec. 6, T. 9 N., R. 26 W., the following section is exposed on a small stream:

Section on stream in sec. 6, T. 9 N., R. 26 W.

	Ft.	in.
Thin-bedded gray sandstones	4	3
Light-grayish blue clay		2
Coal		6
Dark-blue clay		2
Soft black argillaceous shales	5	

The black shales of this section are very friable and easily ground into a paste.

About 3 miles east of Ozark, in the NE. ¼ SE. ¼ sec. 8, T. 9 N., R. 26 W., the railroad cutting has been carried through a bed of white siliceous clay from 4 to 6 feet deep and about 140 yards long. When dry, this clay is white, but becomes bluish when wet. At both ends of the bank the clay loses its whitish color and becomes various shades of red.

RESIDUAL CLAYS.

It has already been pointed out in the chapter on the general geology of the State that the rocks of the coal regions of Arkansas which underlie the surface in Franklin County consist chiefly of alternate beds of sandstone, shale, fire clay, and coal. When argillaceous shales are exposed for a long time to weathering, they disintegrate so completely that they form plastic clays available for the manufacture of pottery, sewer pipes, paving bricks, etc. All the plastic clays found among the hills of Franklin and adjoining counties, especially those found in the upland valleys, have been formed in this way. These rocks were originally deposited as horizontal beds of sediments; but in Franklin County they have been pressed into gentle folds and worn away by erosion until they must be regarded as only the badly mutilated remains of the original deposits. But in spite of this folding and erosion and in spite of the talus of loose fragments and earth that cover the outcrops the beds may be readily traced by means of the geologic structure.

Only a few localities at which potter's clays have been found and worked will be mentioned here, but these clays can be found in abundance in Franklin County if a demand for them should arise.

On the Ozark-Kingston road, running east and west along the south side of sec. 20, T. 10 N., R. 26 W., blue and red shales of Carboniferous age appear in a ditch entering from the creek near the schoolhouse to the lane that turns north along the middle of the same section. These shales appear to be about 6 feet thick. About 30 paces farther north along this lane, in a small artificial opening, they are seen to have disintegrated into a light-blue clay, 3 feet of which is exposed at this place.

A clay or disintegrating shale, which appears to be the continuation of the shales last mentioned, occurs in the N. ½ NE. ¼ NE. ¼ sec. 29, T. 10 N., R. 26 W., as well as in the NW. ¼ NE. ¼ sec. 29 and the NW. ¼ NE. ¼ sec. 28.

TRANSPORTED CLAYS.

At Webb City, in the NE. ¼ NE. ¼ sec. 11, T. 9 N., R. 27 W., a bed of pottery clay is exposed in a ditch along the Ozark-Caulksville road. This clay is almost white, is mottled with small streaks of red, and where exposed has a thickness of 2 feet. Being of Pleistocene age and forming a horizontal bed, it probably has a considerable areal extent. The bed is covered with the usual waterworn cherty gravel and overlies gravelly red clay, which rests unconformably on black Carboniferous shales. The section at this exposure is as follows:

Section at Webb City.

	Feet.
Watertown gravel	2
Pottery clay streaked with red	2
Gravelly red clay	2
Black shales at base.	

The upper gravel of this section is only 2 feet thick where the clay is exposed, but on the hillside south of this exposure it is probably from 15 to 20 feet thick.

BRICK CLAYS.

Enormous quantities of good brick clays lie in the second bottoms of Arkansas River south of Altus, extending eastward along the river as far as the mouth of Horsehead Creek. At some places, as on the road from Altus to Roseville, these brick clays are from 20 to 30 feet thick. The bricks made from these clays are gray in color and spotted with iron.

The area of brick earths around Ozark is limited to a small portion of the NW. ¼ sec. 36, NE. ¼ sec. 35, SW. ¼ sec. 25, and SW. ¼ sec. 26, T. 10 N., R. 27 W.

No bricks have been made at Ozark for several years. The last were made by W. A. Jennings in 1886.

About 1 mile north of the Roseville ferry, near the center of sec. 33, T. 9 N., R. 26 W., the Altus-Roseville road crosses a terrace of reddish, sandy, horizontally bedded clays similar to those of the terraces at Argenta and Fort Smith. At this locality the terrace is about 25 feet high. It may be traced for about 300 yards east of the road to a point where it is cut off by a small stream, and for about 100 yards west of the road. The clay is the same as that used for the manufacture of building bricks at Pendle & Morrison's yards in Fort Smith and at Argenta.

This terrace can no doubt be traced, at about the same elevation, from 50 to 75 feet above the river, for long distances on both sides of the river bottoms, though in many places it has been entirely removed by erosion.

At the church in the southwest corner of the SW. ¼ SE. ¼ sec. 28, T. 9 N., R. 26 W., a well about 30 feet deep shows a surface of yellow sandy clay or loam, while the materials brought up in cleaning show the bottom to be whitish gravels stained with iron.

Near the south line of the section in the SW. ¼ SE. ¼ sec. 21, T. 9 N., R. 26 W., a well 21 feet deep has the following section:

Section in well in sec. 21, T. 9 N., R. 26 W.

	Feet.
Yellow sandy clay or loam	3
Sticky yellow clay	18
Black shale at bottom.	

Some small patches of brick earth occur close to Altus. These vary in extent from 1 to 10 acres. No bricks have been made here for several years.

The following is a section at Altus station, on the St. Louis, Iron Mountain and Southern Railway:

Section at Altus station.

	Feet.
Reddish-brown clay	3
Yellow clay	2
Whitish-yellow clay, visible	1

The colors seem to be the only distinguishing features, as each of the three divisions contains pebbles and their texture is otherwise alike.

In the N. ½ SE. ¼ sec. 16, T. 9 N., R. 26 W., the road passes a band of red sandy clay. It lies upon the slope of a hill, facing north. It is about 150 yards across, but its depth is not known.

At several places around Altus there are disintegrated blue argillaceous shales. On the Roseville and Altus road these shales are among red and blue shales and thin beds of sandstone close to George Page's house, in the SW. ¼ NE. ¼ sec. 2, T. 9 N., R. 26 W., and also in a ditch at a corresponding level in the NE. ¼ SE. ¼ sec. 16.

CLAY INDUSTRY.

In the NE. ¼ NE. ¼ sec. 20, T. 10 N., R. 26 W., J. M. Van Curom at one time manufactured coarse earthenware. The material used was a partially disintegrated red and light-blue argillaceous shale, from 18 inches to 4 feet in thickness, which occurs on the tops of the hills near by. The shale is overlain by a thin layer of gravel, and owing to the difficulty of separating the two the material used in this pottery contained a considerable quantity of small pebbles, which, with the appliances employed, the owner of the shop was not able to remove entirely. The red color of this material is so marked that even when ready for burning the ware has a light-red color.

Only the commonest classes of ware used in the neighborhood, such as churns, jugs, crocks, and jars, were manufactured. A small quantity of 6-inch piping was also made, for chimney flues.

The slip used for glazing was the ordinary black or Albany glaze. The kiln was not suitable for salt glazing. Owing to the general roughness of the ware a great amount of slip was used, leaving a rough surface streaked with slip in different stages of fusion. The construction of the kiln also allowed ashes to settle on the hot ware, where it became fixed by the glazing, thus adding to the roughness of the surface.

The fuel used in this kiln was mostly oak wood, but coal was also used.

These shales make a coarse but strong ware, the loss by firing and drying being about 2 per cent. If they were properly crushed, ground, and screened, there is little doubt that good, strong sewer pipe might be manufactured from them.

GARLAND COUNTY.

About Hot Springs are many beds of argillaceous shales, which in places are decayed to soft, plastic clays. At the spring just below the old Hale bathhouse some of these shales are light colored and have decayed to a buff or dirty cream-colored clay, while the darker shales form on decay a very black, sticky mud.

Where the cut is made for the Government reservoir at the south side of the reservation, the rocks cut are black shales on the south and sandstones on the north. Both shales and sandstones are traversed by numerous quartz veins, and even where the shales have decayed and formed a soft, plastic clay broken quartz veins may be seen. These decomposed beds are injured for practical use by the presence of these small decayed quartz veins, which now remain as strings of angular quartz fragments.

These shales belong with the overlying rocks and are well above the novaculites, which end with the Garland conglomerate bed shown in the quarries on both sides of the avenue above the Hotel Arlington.

No clay industry of any kind is at present carried on in Garland County.

A peculiar form of kaolinite to which the name rectorite[a] has been given is found in Garland County in sec. 27, T. 2 N., R. 19 W. This material is tough and leathery, but it has the smooth, soapy feel so characteristic of the kaolins and of steatite. It occurs in association with the Ordovician sandstones of the region, but the deposits, so far as known, are only about a foot thick.

Analyses of rectorite from Garland County.

[R. N. Brackett, analyst.]

		1.	2.
Silica (SiO_2)		52.72	52.88
Alumina (Al_2O_3)		36.60	35.51
Iron (Fe_2O_3)	(one determination)	.25	.25
Lime (CaO)		.45	.45
Magnesia (MgO)		.51	.51
Potash (K_2O)		.26	.26
Soda (Na_2O)		2.83	2.83
Loss on ignition		7.76	7.72
		101.38	100.41
Water at 110° C		8.78	8.33

Rectorite as it comes from the ground ranges in color from pure white to reddish brown. The sheets are very flexible but entirely without elasticity. It is infusible before the blowpipe, but when heated in the flame of a Bunsen burner it loses water and becomes brittle. Specimens of this kaolinite were sent to ceramic works to be tested practically, and the following report was made on the results by Homer Laughlin, of East Liverpool, Ohio:

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[a] In honor of E. W. Rector, of Hot Springs, who originated the Geological Survey of Arkansas.

> The sample of what you call kaolinite sent me was duly received and carefully examined and tested under fire. The mineral is neither kaolin nor kaolinite, but just what it should be called I am unable to say, never in all my experience having seen any mineral of its kind. Unlike kaolin, it will not dissolve in water. It burns a white color and becomes very vitreous and strong. It can not be finished with a smooth face or skin, but roughs up like a blotting pad. It is certainly a very interesting and curious mineral, but I can think of no use for it in ceramic manufacture unless it could, after careful experiments, be made into novel ornaments.

Samples were also sent to Oliphant & Co., of the Delaware Pottery, at Trenton, N. J., but they were unable to say anything of its quality or market value.

Although rectorite is not now known to have any practical commercial value, it is mentioned here as of scientific interest and of possible future importance.[a]

GRANT COUNTY.[b]

Grant County is almost entirely within the area of the "Lignitic" (Tertiary). The surface is such as is characteristically found in the Tertiary area of this State, being a rolling surface, broken in the vicinity of the larger streams. The soils are sandy and thin on the uplands, while the higher ridges exhibit abundant novaculite gravels, at many places rudely stratified and everywhere small.

The divides are in many places wide and flat, or filled with a series of broad depressions which constitute sandy "slashes." All support a heavy growth of large and fine pine. The bottom lands are characteristically wet and clayey. They support an abundant growth of large white oak, red oak, and gum, with scattered groves of holly.

The general stratigraphy here given is the result of composite sections made up from well records and from sections in gullies and cuts made by streams. Near the mouths of the deeper ravines a sandy clay lies at the base of the hills.

The members of the Eocene (Tertiary) form a considerable portion of the surface of this county. As is well known, these members are largely arenaceous, with an admixture of thin clays of varying colors. Commonly these clays are erratically distributed in the form of small lenticular pockets. The pockets are disposed without observable vertical order, but appear to be most common near the top of the series. Their color is nearly everywhere drab to white, but at some places, especially where heavy beds of sand are superimposed upon them, it is some shade of red.

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[a] A mineralogical description of rectorite was published by R. N. Brackett and J. F. Williams in Am. Jour. Sci., 3d ser., vol. 42, 1891, pp. 16-21.

[b] The notes on Grant County were taken chiefly by R. E. Call and C. E. Siebenthal.

In the NW. ¼ SE. ¼ sec. 35, T. 4 S., R. 15 W., near the mouth of a small tributary of Saline River, there is a bed of light-drab and fine-grained fire clay, underlying a 2-foot bed of lignite. The clay is exposed for about 2½ feet, but its total thickness is not known. The locality is difficult of access and at present without transportation facilities.

The lignite found at this locality has been tried in blacksmiths' forges at Sheridan with indifferent success. Several sacks of it were taken to that village and burned in grates; it is reported to have burned well. On exposure it falls to pieces, eventually becoming a coarse powder, which circumstance would prevent its general use for fuel were it otherwise suitable.

A tough, plastic, gray clay outcrops on E. G. Davis's place, in the SW. ¼ NW. ¼ sec. 25, T. 6 S., R. 15 W. A well 300 yards west and about 25 feet higher went through 25 feet of sand. The well at the gin in Sandy Springs, which is about 400 yards south of the first well, showed from 8 to 10 feet of white sand. The road for 1½ miles southwest of Sandy Springs shows red sand but no gravel. At one place the sand much resembles chocolate clay.

About 20 feet of a dark sandy clay outcrops in a stream bank in the SW. ¼ NW. ¼ sec. 31, T. 6 S., R. 14 W.

Stephen Heard's well, near the northwest corner of the SW. ¼ sec. 31, T. 6 S., R. 15 W., shows the following section:

Section of Stephen Heard's well.

	Feet.
Red clay	15
Potter's clay	7
Red clay	8
White gravel (some bowlders as large as a man's head)	5
Clays of different colors, the lowermost containing leaf impressions	31
White sand	3
	69

Plastic clay is reported near the southwest corner of sec. 18, T. 6 S., R. 15 W.; also on the Davis farm, near the center of sec. 10, in same township. A very white plastic clay is reported to occur in same township near the schoolhouse in sec. 9, about the middle of the west side, on a small drain flowing into Brushy Creek.

Plastic gray clay outcrops in the NW. ¼ NW. ¼ sec. 31, same township, in a drain flowing south in Gum Bottom. Similar clay which has been used for pottery outcrops in drains and is exposed on the breaks of the hills farther east all along the north side of Gum Bottom.

Section of well at Sheridan.

	Feet.
Light sandy soil with abundant novaculite pebbles; occasionally clayey	3
Small, waterworn novaculite gravels, with much purplish quartzite; rudely cross-bedded and stratified	13
White sand, with lenticular pockets of drab, red, or yellow clay; pebbles rare toward the top	43
Blue to black horizontally stratified clay, containing in its partings abundant lignite particles and mica scales. Well sections commonly end in this member, which has at no point been penetrated, at 8 to 10 feet below the top.	

In the roads from Benton to Sheridan and from Sheridan to Pine Bluff, near the top of every hill which is crossed, there are thin layers of a red or yellow ocherous clay which has nowhere been found in heavy beds. The same clays are found on the faces of the higher bluffs near all the streams and form a conspicuous feature of all the deeper washes.

Limonitic or buckshot brick clays similar to those used at Malvern occur in the bottoms of all the streams, especially in those of Lost, Hurricane, and Darysaw creeks, and in that of Saline River. The distribution of these limonitic clays is well defined. They skirt the bases of all the hills and extend over the bottoms of all the creeks and deep branches, forming the roadbed in all such localities. The cold and wet character of the bottom lands is due to their presence, for water does not readily percolate through them. Throughout the bottom lands they rise here and there to the surface in barren patches. A map of the region including the river and creek bottoms would be a map showing the distribution of the limonitic hardpan or buckshot clays.

The pine flats or pine slashes of the higher lands are of a sandy, drab-colored clay, which is used locally for building chimneys. In one place, at Sheridan, it has been employed in the manufacture of rough bricks. The clay is not well suited to this use, containing too much sand, too little iron, and burning to a poor color. The jail at Sheridan is built of bricks made from this clay—the only kiln of brick known to have been made in the county.

The region along Saline River, especially at the base of the bluffs, gives most promise of exhibiting deposits of fire and pottery clays, this region being the one that best exposes the deeper lying Tertiary clays.

At numerous localities throughout Grant County, and notably in the SW. ¼ SW. ¼ sec. 11, T. 5 S., R. 13 W., there is a highly ferruginous sandstone at places attaining a thickness of 1 foot. This rock occurs commonly well up on the sides of the hills and not infrequently caps their summits. In other localities the gravels are conglomerated, or cemented, with iron oxides, and may be removed in large masses from the hills. Both sorts are locally used for underpinning houses and barns, and occasionally for building chimneys. In a region where other hard rock is entirely wanting, these beds appear to be very valuable for both these uses.

The water from the wells has a bitter saline taste, due possibly to epsom salts (magnesium sulphate) or to sulphate of iron. Only water coming from the numerous springs along the contact line between the gravels and the underlying clays or clayey sands appears to be free from this bitter taste.

It is believed that the beds underlying the surface members are equivalent to those at Camden.

No plant of any kind in the county is engaged in the manufacture of brick or other clay products.

GREENE COUNTY.

GENERAL GEOLOGY.

Greene County is divided into three natural topographic provinces—the St. Francis River sunken lands on the east, Crowleys Ridge in the center, and the Cache River bottoms on the west.

The St. Louis, Iron Mountain and Southern Railway from Jonesboro to Piggot runs along the second bottom land on the east side of Crowleys Ridge. The second bottom land is formed of reworked material derived from Crowleys Ridge. It is a yellow-clay soil, well adapted to the cultivation of wheat and corn. At Paragould the yellow-clay land extends about 2 miles eastward from the foot of the ridge.

East of the yellow-clay second bottom land comes a narrow band of glady clay soil which extends eastward for about 2 miles. The clay that forms this strip is a white to gray joint clay or pipe clay, which is very tough when wet but pulverizes completely when turned by the plow and exposed to the sun and rain. In texture the soil is very similar to that of the second bottom to the west.

The western edge of the white glady land marks the western limit of high water of St. Francis River. Until recent years backwater from the river would stand on the land until the iron oxide had been leached out so as to leave the soil cold and lifeless. Where the land has been drained and the water kept from standing on it, the soil within three to four years assumes a brown to yellowish color and becomes more productive.

The soil of the country east of the glade land is composed of fine silt and sand. The sandy land stands 8 to 10 feet lower than the white glady land to the west.

The Tertiary rarely appears at the surface along the eastern edge of Crowleys Ridge in Greene County, but is covered by later deposits, consisting of Lafayette gravel and sand and loess. In one of the wells at Paragould the Tertiary was encountered below 20 feet of yellow clay and about the same thickness of iron-stained gravel (Lafayette).

On the western edge of the ridge the Tertiary sands, interstratified with variegated clays, occur at various places along the steep and in places almost vertical cliffs.

The hard quartzose sandstone ledges which are found at the foot and on the sides of the ridge near the railroad, in the northwestern part of Craighead County, outcrop in no less than five localities in Greene County. One occurs on the line between Greene and Craighead counties, one near Walcott, one near Crowley, one west and another northwest of Gainesville, and still another is reported 3 miles west of Paragould. At each place the sandstone is similar in appearance to the Tallahatta of central Mississippi, but its exact age is as yet unknown.

Buckshot clay lands and the sandy bottom land of Cache River bottom occupy the country to the west of Crowleys Ridge.

CLAY INDUSTRY.

The only clay used in the county for other than agricultural purposes is the loess and reworked loess used in the manufacture of bricks at Paragould and Gainesville. A sample was taken from the loess at the village of Gainesville, where it is employed in the manufacture of bricks. It is hardly a typical loess, but it is closely allied to it.

Analysis of loess used for brickmaking at Gainesville.

[Dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	81.34
Alumina (Al_2O_3)	9.71
Ferric oxide (Fe_2O_3)	3.67
Lime (CaO)	.29
Magnesia (MgO)	.33
Manganese (MnO)	Trace.
Alkalies, by difference	1.55
Loss on ignition	3.11
	100.00
Air-dried sand in air-dried specimen	35.00

The deposits from which this sample came lie on the slope of a hill, the base of which is composed entirely of Tertiary partly colored sands. Except for the small percentage of sand in the air-dried specimen and the greater oxidation of the iron this soil does not differ materially from typical loess.

The bricks from the plant of the Paragould Brick Company are made from the reworked loess. Dry-pressed and wet-mud bricks are made. The clay for the wet-mud bricks is tempered and molded by steam, dried in covered racks, and burned in updraft clamp kilns. It requires about seven days for drying and fourteen days for burning. Wood is used for fuel.

Two kinds of clay are present in the pit. The upper, porous yellow stratum is best adapted for making brick. The lower stratum is a compact, plastic gray clay which can not be used for brick without being mixed with the overlying yellow clay. When used alone it checks badly in drying. The wet-mud machine has a capacity of 20,000 bricks a day.

The clay for the dry press is stored in a dry shed for several weeks and is then molded into bricks and set in an updraft kiln. It requires about seventeen days to burn the dry-press bricks. The machine has a capacity of 15,000 bricks a day. About 50 per cent of the bricks made at Paragould are sold at the kiln; the remainder are shipped to neighboring towns.

The following analysis was made from the reworked product of the loess at Paragould:

Analysis of brick earth from the surface at Paragould.

[Dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)		79.07
Alumina (Al_2O_3)		8.79
Iron (Fe_2O_3)		2.54
Lime (CaO) Magnesia (MgO) Alkalies	(by difference)	2.37
Manganese (MnO)		3.68
Loss on ignition		3.55
		100.00
Air-dried sand in air-dried clay		43.64

The percentage of iron found in analyses of Greene County clays is commonly sufficient to give the bricks a deep shade of red. In analyses of clay from Paragould only a trace of manganese appears. The red color of bricks made from loess clays, therefore, seems to be due to the iron alone. To get brown colors it will be necessary to add manganese-bearing clay. Lime and other alkalies form an inconsiderable portion of the whole clay. From these loess soils the best quality of pressed brick may be made. This has already been practically demonstrated at many places along the upper Mississippi River.

HEMPSTEAD COUNTY.

GENERAL GEOLOGY.

In its general features the geology of Hempstead County is very simple. The rocks of the northern part of the county are upper Cretaceous, while those of its southern part are Tertiary. The upper Cretaceous rocks are covered with great beds of waterworn material—cobblestones, pebbles, and sand. This gravel is especially abundant about Bingen and between Nashville and Hickory Creek.

The line of juncture between the Cretaceous and the "Lignitic" (Tertiary) where the latter overlaps the former enters the county at a point northeast of Hope, south of the railroad, and, following a generally southwest direction, crosses Bois d'Arc Creek about 4 miles southeast of Fulton. South of this line everything in the county is Tertiary, except, of course, the alluvial flood plains of the streams and the occasional patches of Pleistocene materials. The Cretaceous, however, dips to the southeast beneath the Tertiary, and deep wells sunk in any part of the Tertiary region must sooner or later strike the Cretaceous rocks. As elsewhere in the State, the Tertiary beds are mostly soft and are disposed in horizontal or nearly horizontal strata. The whole of this Tertiary part of the county has been more or less denuded, but in some places the streams have cut out the beds to make the valleys, leaving the remnants of these beds in the hilltops, where they are covered with a thin coating of sand, gravel, and loam.

CLAY DEPOSITS.

In southern Hempstead County, as elsewhere in the Tertiary regions, pottery clays are found in patches. This fragmentary nature of the pottery clay deposits may be due either to the original pockety nature of the sediments or to subsequent erosion, which has removed a great part of the original clay beds. In prospecting to determine the extent of known deposits these points should be determined first and prospecting carried on accordingly.

The pottery clay deposits of Hempstead County, so far as they have been practically tested, are best known in the neighborhood of Spring Hill, a town about 6 miles south of Hope, and in T. 13 S., R. 24 W., 4 miles south of Hope.

CLAY INDUSTRY.

Foley pottery.—There was formerly a small pottery 4 miles south of Hope, operated by John Foley. The clay was obtained from a bank opened in the NW. ¼ SE. ¼ sec. 18, T. 13 S., R. 24 W. The clay deposit is about 150 yards in diameter, as shown by test pits, and aggregates 14 feet in thickness. It is divided into two beds, an upper one, 4 feet thick, of a clay that is of bluish color when wet, but nearly white when dry. This bed contains seams of indurated or slaty clay, so hard as to require grinding. The lower bed of clay is 10 feet thick, and when wet is of a pinkish hue. It contains some iron stains and weathers to a yellowish color.

The upper one of these clay beds was used for the manufacture of flower pots and the various classes of pottery demanded in the district. The lower bed was used exclusively for making fire bricks. Bricks made from this clay are light and porous, and are of a cream color. To render the clay porous enough for brick manufacturing sawdust was mixed with it before molding.

Analyses of the clays used by Mr. Foley in the manufacture of pottery and fire bricks are given below. Each specimen analyzed was dried at 110°–115° C.

Analyses of clays from beds near Hope.

[Brackett & Smith, analysts.]

	1.	2.	3.
Silica (SiO_2)	76.33	73.87	72.48
Alumina (Al_2O_3)	16.04	17.38	18.24
Ferric oxide (Fe_2O_3)	1.24	1.64	1.52
Lime (CaO) Magnesia (MgO) Potash (K_2O) Soda (Na_2O)	.99	1.46	1.98
Loss on ignition (H_2O)	5.40	5.65	5.78
	100.00	100.00	100.00
Sand	13.00	....	3.62
Water at 110°–115° C	2.23	1.92	1.69

Other clays suitable for the manufacture of fire brick may be found within a short distance of the Foley pit.

Spring Hill pottery.—Before the civil war a small pottery was operated at Spring Hill, where several beds of clay are available for pottery.

At present (1906) a pottery is operated near Spring Hill by Michael Foley. Tertiary clays, such as those used at Texarkana and Benton, are used for the manufacture of jug ware, crocks, and churns.

Hope brick works.—A large brick plant was established at Hope in 1904 by Messrs. R. E. and N. P. O'Neal. Common building bricks are made. The bricks are molded by steam in a Hercules Senior machine, dried by the pallet and rack system, and burned in updraft clamp kilns. The length of time required for drying depends on the weather. About ten days are necessary for burning. The fuel used is wood. Three kilns are used. The bricks are made from the surface clay. The plant has an output of 32,000 bricks a day.

HOT SPRING COUNTY.

GENERAL GEOLOGY.

The Tertiary border enters Hot Spring County from the northeast, in Saline Township, and crossing the Hot Spring Railroad a mile south of Butterfield and Ouachita River at Rockport, passes into Clark County a few miles above the mouth of Bayou de Roche. To the south and east of this line lie the nearly horizontal Tertiary beds, while to the north and west the county is mountainous and the Paleozoic rocks are much folded, broken, and eroded. Though it is not impossible that pottery clays may be found among the disintegrated shales of the hilly regions, the Tertiary is eminently the region of pottery clays, not only in Hot Spring County, but in the whole State of Arkansas.

The Tertiary formations have been denuded in Hot Spring County, as elsewhere, so that the uppermost beds, being deeply scored by gullies, ravines, and valleys, are more or less fragmentary. Where the pottery clay beds belong with this uppermost group they have been exposed in the sides of the hills, but their margins have been covered and concealed by the less soluble and less portable remains of the overlying beds and by waterworn materials of Pleistocene age. The structure of the region is thus obscured in spite of its great simplicity, and for this reason the pottery clays have been found only where they happen to be uncovered by some natural process, as in the channel of a stream, or artificially along roadsides or in wells.

CLAY DEPOSITS.

PERLA SWITCH CLAYS.

The only place at which the Tertiary pottery clays are known to have been worked in Hot Spring County is at Perla switch, about 2 miles east of Malvern station on the St. Louis, Iron Mountain and Southern Railway. At this place Messrs. O. C. Atchison & Co. manufacture the ordinary kinds of common pottery ware, such as churns, jars, crocks, jugs, fruit jars, sewer pipes, flue linings, and fire bricks. The clay is obtained from a bank on the west side of a small stream in the NE. ¼ SE. ¼ sec. 24, T. 4 S., R. 17 W.

The section on page 113 shows the relation of the pottery clays of Atchison's pit to the hill on the west and south.

The clays are covered by 3 to 5 feet of gravelly, sandy soil, the pebbles of which are principally of quartz and novaculite.

The upper part of the clay bed has occasional pockets of pebbles, formed in cavities made by the decay of roots and stumps, the upper gravel having fallen into these openings.

The light lead-colored clays forming the upper part of the clay bed merge into mottled clays below, and these in turn are followed by snuff-colored layers, while the lowest part of the bed visible is a dark-brown mucky looking clay. Fossil leaves occur only in the two lower members. If they ever existed in the upper part of the clay they have been destroyed by the action of percolating water.

The depth of this clay bed was tested with an earth auger and was found to be 30 feet. The bed is more sandy below, however, and contains some iron pyrites, which injures it for pottery making.

The light-colored upper part (10 feet) of Atchison's clay pit is used chiefly for the manufacture of pottery. This clay burns to a hard, solid body and is easily glazed with either the Seneca Falls or Albany slip clay or with salt. The lower bed, which consists of dark clay, is utilized for the manufacture of fire bricks, sawdust being mixed with the clay to give the bricks the necessary texture and porosity. This clay burns to a light-cream color and the ware has a remarkable bell-like, metallic ring.

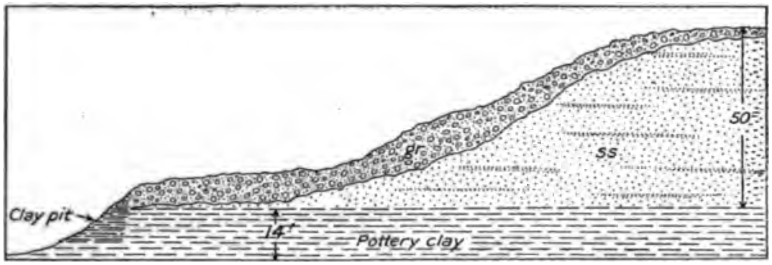

FIG. 11.—Section at Atchison's clay pit at Perla switch, Hot Spring County. *ss*, Sandstone; *gr*, gravel.

Analyses of clays from Perla switch.

[Brackett & Smith, analysts.]

	Light-colored pottery clay.	Dark-colored brick clay.
Silica (SiO_2)	73.24	72.59
Alumina (Al_2O_3)	19.61	16.08
Iron (ferric) oxide (Fe_2O_3)	1.04	1.18
Lime (CaO) Magnesia (MgO) Potash (K_2O) Soda (Na_2O) (by difference)	.78	3.81
Water (H_2O)	5.33	6.34
	100.00	100.00
Water at 110°-115° C	2.01	2.08
Fine white sand	5.40	....

On John Wilkerson's land in the N. ½ NE. ¼ sec. 35, T. 4 S., R. 17 W., there is a deposit of light-colored pottery clay from which the

Atchison Company formerly obtained its supply. This clay has been recently tested for fire bricks by the Clark Pressed Brick Company, of Malvern. It is thought that it will prove of excellent quality for this purpose.

OTHER CLAYS.

The topography of the country about Perla switch and the disposition of the Tertiary beds lead to the belief that the pottery clays found at the Perla pits may also be found on the northwest side of the railroad. Similar beds may reasonably be looked for on both sides of the railroad at Traskwood, and along the line of hills northwest of the road. These clays, however, may vary locally somewhat, both in character and in thickness, here disappearing altogether and there forming thick pockets, but are probably rather constant in geologic position.

The gravel and sand covered ridge south of Malvern is of the same geologic structure as that at Perla switch, and similar pottery clays might reasonably be expected almost anywhere in that region.

West of the ridge on which Malvern stands a dark clay containing more or less lignite is found in wells. The following is the record of a well in sec. 22, T. 4 S., R. 17 W.

Section in well west of Malvern.

	Feet.
Gravel	12
White clayey gravel	2
Black lignitic clay	13
	27

The black clay was not completely penetrated in this well, and its thickness is not known. The bed may be the equivalent of the beds worked at Perla switch. The same bed has been found in other wells in section 22.

A sample of this clay was burned with the following results:

Test of clay from sec. 22, T. 4 S., R. 17 W., showing loss on ignition.

	Feet.
Water and volatile matter	17.44
Fixed carbon	5.61
Total loss	23.05

A large bed of light-colored or white clay underlies the gravel bed in the rear of Orr's Commercial Hotel at Malvern and extends southward along the hills for several hundred feet and northward nearly across the street next east of the hotel. It varies from 6 to 8 feet in thickness, and is almost pearly white, streaked with yellow or brown—the color being produced by infiltration of iron-charged waters along cleavage joints. It is not known whether the bed has been reached in wells farther east.

The well dug for the planing mill at Rockport is said to have passed through a bed of potter's clay before reaching the fossiliferous limestone, but this clay has not been examined.

The following is the section of A. Parrish's well, near the center of the NE. ¼ sec. 7, T. 6 S., R. 17 W., as reported by Mr. Siebenthal:

Section in well of A. Parrish.

	Feet.
Red clay	1
White clay	8
Darker clay	2
Lignite	1
White clay	2

In the NE. ¼ sec. 5, T. 6 S., R. 17 W., according to Mr. Siebenthal, the Clarkson-Christopher Lumber Company's tramway cuts 20 feet of slaty-blue plastic clay which weathers very much like the olive-green clays of Little Rock. This clay contains leaf impressions. The locality is 460 feet above tide.

The following is the section record of Ford's well in the SE. ¼ sec. 33, T. 5 S., R. 17 W.:

Section of Ford's well.

	Feet.
Soil and gravel	24
Tough bluish clay	2
Sand in bottom.	

White plastic clay is reported on a small stream in the SE. ¼ sec. 3, T. 5 S., R. 17 W. Mr. Siebenthal is of the opinion that it is good potter's clay.

The following is a record of the well section at Kramer's, in sec. 19, T. 6 S., R. 17 W. This place is 430 feet above sea level (barometer):

Section of well at Kramer's.

	Feet.
Soil and gravel	10
Blue clay	15
Lignite	2
Blue clay	11
Lignite	2
Hard gray clay	2
Lignite in bottom.	

In the NE. ¼ sec. 35, T. 6 S., R. 18 W., about a quarter of a mile above Sulphur Springs, Mr. Siebenthal reports 4 feet of dark-gray clay exposed in the bank and bed of the creek. The weathered upper part of this bed is dark and is said to resemble the clay in the Perla switch beds above Malvern. It is said that some of this clay has been successfully used for manufacturing pottery. A practical test of it was made by the Rev. Mr. Clark, who burned it on the west side of the Ouachita, below Rockport.

In addition to the localities mentioned above, it is highly probable that fine pottery clays are widely distributed throughout all of that part of Hot Spring County lying south and east of the St. Louis, Iron Mountain and Southern Railway.

MAGNET COVE KAOLIN.[a]

The rocks of the Magnet Cove are largely feldspathic, and in places they are decomposed to great depths. The only kaolin found in Magnet Cove, however, occurs in a few small scattered bands and patches, while the residuary clays as a whole are full of grit, iron oxide, and incompletely decayed fragments of mica. These clays are not available for brickmaking, and even the earth used for lining chimneys is hauled from the region of sedimentary rocks outside of the cove.

A well 49 feet deep, dug at the residence of J. F. Moore, in the SW. ¼ NE. ¼ sec. 19, T. 3 S., R. 17 W., is all in eruptive rock, decayed in place, much of which is soft enough to be removed with the spade. Only very thin streaks of kaolin were found in this decayed rock.

A small deposit of kaolin is uncovered east of I. N. Johnson's house, in the southeast corner of the cove, NW. ¼ NE. ¼ sec. 29, T. 3 S., R. 17 W., and a few layers are exposed in the Hot Springs road at the west end of the cove near Thomas Holt's house, and also in his well, NE. ¼ NE. ¼ sec. 24, T. 3 S., R. 18 W.

At John Neusch's house, NW. ¼ NE. ¼ sec. 30, T. 3 S., R. 17 W., small streaks of kaolin, perhaps 2 inches wide, were found in digging a well. The earth taken from Mr. Neusch's well was examined shortly after the well was dug. The little lumps of kaolin in it are of excellent quality, but there is nothing to lead one to expect to find it in workable quantities. Afterward lumps of this kind of kaolin were sent to the office of the State survey for examination, with the report that there was an inexhaustible quantity of it, but following up this rumor it was found that the sample came from Mr. Neusch's well. None of these small deposits have any economic value. It is possible, however, that kaolin may yet be found in Magnet Cove in quantities and of a character that will render it valuable. This possibility is suggested by the nature of the rocks and by their profound decomposition.

Bringier speaks of china clay in the "Wichita" cove,[b] and Doctor Owen mentions beds of kaolin from 3 to 15 feet in thickness.[c] These reports have not been confirmed. The places referred to by Owen were "in wells dug by George Piles and Mr. Plank;" if the locations can be found it may be well worth while to verify the matter.

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[a] The geology of the Magnet Cove region is discussed in detail by Dr. J. Francis Williams in Ann. Rept. Survey Arkansas for 1890, vol. 2.

[b] Bringier, L., Am. Jour. Sci., 1st ser., vol. 3, 1821, p. 26.

[c] Owen, D. D., Second report of a geological reconnaissance of the middle and southern counties of Arkansas in 1859 and 1860, p. 162.

CLAY INDUSTRY.

Clark Pressed Brick Company, Malvern.—The plant of the Clark Pressed Brick Company is located near the main track of the St. Louis, Iron Mountain and Southern Railway, on the south side of the town of Malvern. The bricks when burned are loaded directly from the kilns into cars.

The clay used for making the brick is obtained from the second-bottom hummock of Ouachita River, about three-fourths of a mile from the kilns. A steam shovel is used in the pit for digging the clay, which is loaded into small cars. The cars are drawn to the kiln on a steel-railed tramroad by means of a small locomotive.

Through the summer and fall the common stiff-mud bricks are made, and dry-pressed brick during the winter. The clay is high in silica, burns to a deep Indian red color, and makes a durable, tough brick.

The bricks are made in an end-cut machine and dried in an artificial drier. The green bricks are then placed in large 250,000 up-draft kilns. It requires seven days for burning a kiln, using 110 tons of coal.

The plant has a capacity of 75,000 bricks a day. Forty-eight men are employed; two men in the pit, one man to run locomotive, six men in setting dried bricks in the kilns, and the remainder in feeding pug mill, carting green bricks away to drier and, when dried, to the kilns, running machinery, loading burned bricks, and firing kilns.

Malvern brick and tile works.—This plant manufactures white front, paving, and fire bricks. The white plastic clay, which is doubtless of lower Tertiary age, is used. The bricks are made in a stiff-mud machine and dried with artificial heat. The bricks are burned in round down-draft kilns.

JACKSON COUNTY.

The greater part of Jackson County lies east of White River and its principal tributary, Black River. These two rivers in this county practically mark the eastern border of the old Paleozoic rocks. The greater portion of the county is therefore in lowlands of Quaternary age. Two townships that lie directly south of Independence County are mostly in the Paleozoic area. A narrow ridge west of Depart Creek in T. 10 N., R. 4 W., contains limestone and marl bearing a fauna that belongs to the midway stage of the Tertiary. The Tertiary is recognized in but one place north of this, namely at Newark, where a bed of greensand marls has been found containing shark's teeth and some unrecognizable invertebrate fossils.

The surface of the lowland is similar to that of most of the counties in the Quaternary of this section of the State. Near the streams there are large sand ridges of alluvial origin with a subsoil of yellow to buckshotty clay. In places these alluvial deposits extend 4 to 6 miles back from the stream. Abandoned streams can likewise be traced by old channels, with alluvial deposits extending for a greater or less distance on both sides. Some of these old channels now form lakes.

It appears that the surface of the country was originally very nearly level, with but slight depressions, sufficient to determine the location of the drainage streams. Repeated overflows carried large quantities of alluvium, which was deposited as sand ridges near the streams. The ridges farthest removed from the streams or abandoned channels are all higher than the prairie lands. The soil of the prairie lands is generally a yellowish to gray clay, in places containing more or less fine sand. The difference between the two soils is likewise marked by differences in species of virgin timber and differences in the character of crops produced. The alluvial soil is generally much more fertile than the prairie soil.

No clay products of any kind are manufactured in Jackson County. Brick clays are available at Grand Glaise, in the southwestern part of the county. The loam that forms the prairie lands back from the streams, especially in the central part of the county, could be made into common building brick. A clay subsoil that outcrops in the bank of White River at Newport is suitable for making a good building brick.

JEFFERSON COUNTY.

CLAY DEPOSITS.

The greater part of Jefferson County is covered by alluvial deposits of Arkansas River and of Bayou Bartholomew. Running along the western edge of the county, however, is a strip of the Claiborne (?) formation (Eocene), having a width of 10 or 12 miles. In the river bottoms brick clays occur here and there and in some of the slashes there are occasional patches of clay available for the manufacture of cheap grades of pottery, but the best clays of the county are in the western tier of townships. At a place called White Bluff these Tertiary beds are well exposed on Arkansas River. The accompanying section recorded at that place shows the relations of the clays to other beds.

Section at White Bluff, on Arkansas River.

	Feet.
1. Soil and sand	8
2. Light-gray sandy clay	9
3. Light-pink clay with fossil leaves	8
4. Laminated dark shaly clay	9

	Feet.
5. Dark lignitic clay with two bands of lignite	5–9
6. White sand	4–8
7. Laminated dark shaly clay	11
8. Dark-bluish sandy marl	22

Of the clays exposed in this section No. 3 is probably the most promising. They are well worth testing in any case. The nearness of these beds to water transportation on Arkansas River gives them additional importance.

These beds may continue across the country and at other places may be found under a thinner covering than that overlying them at this place.

CLAY INDUSTRY.

Pine Bluff.—Six yards were formerly engaged in the manufacture of soft-mud bricks at Pine Bluff. The bricks were all made by hand and dried in open yards. In many instances the bricks were insufficiently dried and burned, and as a result a very common and inferior product was made. These yards have all sold out, quit business, or consolidated, and at present there are but two plants doing business in the city.

Pine Bluff Brick Company.—This plant was incorporated in 1892. Common soft-mud bricks are made. The bricks are molded by steam in a Hercules Senior machine, and dried artifically thirty-six hours in a Standard drier. Six to seven days are necessary for burning after they are thoroughly dried. They are burned in up-draft kilns, which have a capacity of 375,000 to 400,000 bricks. Wood is used for burning, about three-fourths of a cord per thousand bricks being used. The capacity of the plant is 40,000 bricks a day. The bricks are made from a sandy surface clay. Size of green bricks 2½ by 4¼ by 9 inches; shrinkage, none.

Conley brick plant.—A small brick plant is operated by J. H. Conley at Redfield, in the northwestern part of the county. The plant was established in 1898. The bricks are made from the common yellow surface clay. They are dried in the sun and burned in an up-draft kiln of 50,000 capacity. The bricks are sufficiently dried in two days to place in the kiln, and are burned in about seven days. Hard wood is used as fuel, about one-half cord being used for burning a thousand bricks. When thoroughly burned the shrinkage in a kiln 10 feet high is about 6 inches. The daily capacity of the machine is 5,000 bricks.

O'Neal & Rogers plant.—A plant has recently been established at Pine Bluff by Messrs. O'Neal & Rogers, but no particulars concerning it were obtained.

JOHNSON COUNTY.

GENERAL GEOLOGY.

The geology of Johnson County is similar in its broader features to that of Pope County to the east, of Franklin on the west, and of Logan on the south. The rocks are of the same geologic age, but there are not the same strong contrasts between the different formations that characterize either Pope or Logan counties. The rocks are chiefly sandstones, shales, and coals. The lowest rocks in the county are exposed in the bottoms of the narrow valleys of the northern part of the county, on the headwaters of Mulberry River and of Little Piney Creek, and about Fort Douglas on Big Piney Creek. The rocks of the lofty mountains about Melson, Ozone, and Mount Levi, although they are much higher than those of the valleys about them, are nevertheless geologically lower than the coal-bearing beds of the Arkansas Valley about Clarksville and Coal Hill.

CLAY DEPOSITS.

CLAY SHALES.

The clays and clay shales of Johnson County that are likely to have economic value lie along the line of the Little Rock and Fort Smith Railway and along or near Arkansas River. The shales of other parts of the county are just as good intrinsically as those near transportation, but owing to the expense of getting them into market they are necessarily of less importance. For this reason but little is said here in regard to the clays and clay shales of the more remote parts of the county.

The Hartshorne sandstone bed, which forms Ouita Ridge, in Pope County, continues westward into Johnson County, forming the broad ridge east and north of Piney station. Those same sandstones continue northward through the eastern section of R. 22 W. South of Arkansas River this sandstone forms the great ridge 2 miles due south of Piney station. The Spadra shale, containing the Ouita coal bed, forms a narrow trough south of Piney station. This trough widens abruptly toward the west and north, so that the Spadra shale underlies all the country west of Piney and west and north of Knoxville for 8 miles or more. These same shales are exposed in the lower portions of the hills east and south of Clarksville, along the valley of Spadra Creek, west of the mouth of that stream to Spadra and Montana, about the base of Spadra Hill, at Hartman, and along the base of the hill just north of Hartman. Throughout this entire area of the Spadra shale clay shales available for the manufacture of paving bricks, sewer pipe, and fire-clay goods may be found, and at many places they are conveniently exposed.

These shales are at some places hard and at others are soft and plastic. Where they have not been exposed long or favorably they are liable to be hard. In places they are disintegrated to a depth varying from 1 foot to 10 feet. Where these shales are soft and plastic they may be used without grinding for the manufacture of fire bricks, stove linings, paving bricks, and sewer pipes. If the shale is not soft and plastic it can be used only after being ground.

The clays and clay shales usually accompanying the coal beds are liable to prove valuable as fire clays.

The clay underlying the coal at the Stiewell mine No. 2 at Coal Hill is hard and shaly when freshly mined but readily breaks up under the influence of the weather. When burned this clay becomes white. Its thickness is uncertain, but it is said to range from 12 to 18 inches.

At the Allister slope at Coal Hill the flooring is said to be a hard black shale, but no definite information could be obtained regarding its thickness. The waste material brought to the top contains a great quantity of black shale with plant impressions.

At Payne's mine a clay from 4 to 6 inches thick underlies the coal. The upper half inch to 4 inches is a soft, dark shale and the lower 1 to 2 inches is a soft yellow clay.

The floor of the Felker mine is a soft shale, sagger clay. It is irregular in thickness, but averages from 4 to 5 feet. In some places in the mine this clay overlies the coal to a thickness of from 2 to 4 inches.

One mile northwest of Knoxville, on the Little Rock and Fort Smith Railway, the railway grade cuts a promising-looking exposure of shales.

At Hartman station the railway has exposed the shales in a cut.

In sec. 32, T. 10 N., R. 23 W., in the bank of the stream that runs south along the east side of the road near Clarksville College, the following section is exposed:

Section in sec. 32, T. 10 N., R. 23 E.

	Ft.	In.
1. Dark-brown shale	2	
2. Disintegrated shale	1	4
3. Coal		1
4. Blue and snuff-colored shales (about)	15	
5. Black shales at the base.		

The following is an analysis of some of the clay produced by the disintegration of Nos. 1 and 2 of the above section, obtained from ditch at W. J. James's, in the southeast corner of the NW. ¼ SE. ¼ sec. 32, T. 10 N., R. 23 W.:

Analysis of distintegrated shale from sec. 32.

[Brackett & Smith, analysts.]

Silica (SiO_2)	55.36
Alumina (Al_2O_3)	26.96
Ferric oxide (Fe_2O_3)	5.12
Lime (CaO)	.30
Magnesia (MgO)	1.16
Potash (K_2O)	2.69
Soda (Na_2O)	1.03
Loss on ignition (water)	7.90
	100.52
Water at 110°-115° C	3.90

A specimen of blue clay shale overlying a 2-inch bed of coal collected by Mr. William Kennedy northwest of Clarksville in the SE. ¼ SW. ¼ sec. 31, T. 10 N., R. 23 W., has been analyzed by the Arkansas Geological Survey.

Analysis of disintegrated shale from sec. 31.

[Brackett & Smith, analysts.]

Silica (SiO_2)	51.30
Alumina (Al_2O_3)	24.69
Ferric oxide (Fe_2O_3)	10.57
Lime (CaO)	.32
Magnesia (MgO)	.63
Potash (K_2O)	2.18
Soda (Na_2O)	.72
Loss on ignition (water)	9.11
	99.52
Water at 110°-115° C	4.92

The section exposed where this specimen was taken by Mr. Kennedy is given below, and the specimen analyzed was from No. 2 of the series.

Section in SE. ¼ NW. ¼ sec. 31, T. 10 N., R. 23 W.

	Ft.	In.
1. Waterworn gravels	1	
2. Blue and yellow shales	8	
3. Coal		2
4. Blue shales with red streaks	4	
5. Black shales at base of section.		

The abundance of clays and clay shales in Johnson County and their proximity to good coal and to transportation both by railway and by water insure facilities for the extensive manufacture of paving bricks, sewer pipes, and fire-clay products.

BRICK CLAYS.[a]

So far as the Clarksville brick earths are concerned, there is but one bed that requires attention. Bricks were formerly made by W. P. Farrish in his yard north of the town, in the northeast corner of the SW. ¼ NW. ¼ sec. 32, T. 10 N., R. 23 W. These appear to be good sound bricks of a rather dark-gray color, very similar in appearance to the bricks made at Beebe and elsewhere along the Iron Mountain Railway. They hold their color well, for bricks used in buildings erected in Clarksville as long ago as 1878 still have a good color. The material from which these bricks were made is not very plentiful nor of a great extent, being confined principally to the flat tops of a few ridges. It is underlain by a lighter-colored earth containing great quantities of iron in the form of nodules ranging in size from that of a pea down to that of bird shot. This underlying material, although of excellent quality for making hard, blue bricks, can not be worked by hand in the same way as the upper clays. The iron nodules are so small that the ordinary mill or wheel will not crush them. They slip through the tempering untouched, and, although not very hard, have a tendency to tear the hands of the molder. Before this clay can be utilized it must be tempered by being passed through rollers set sufficiently close to crush the nodules completely. The clay must afterward be thoroughly mixed so as to disseminate the crushed iron throughout the mass, and thus to bring the whole to a uniform consistency and color. The bricks can then be formed either by hand molding or by machine. This clay, however, could be worked better by machine than by hand, and if such a tempering machine as the one here suggested were used an extensive area covered by this "buckshot" clay close to Clarksville station could be utilized for brickmaking.

No bricks have been made at Coal Hill and very few are used for any purpose, building stone being generally employed for chimneys or other mason work.

In the vicinity of Coal Hill an area comprising the NE. ¼ S. ½ sec. 20, the greater portion of sec. 21, the SE. ¼ and part of the SW. ¼ sec. 19, and parts of secs. 28, 29, and 30, T. 9 N., R. 25 W., are covered by a light brownish-yellow clay averaging about 2 feet in thickness. This clay contains nodules of iron, some of which are soft enough to be crushed between the fingers, and also a quantity of small sandstone pebbles. This clay rests upon soft, friable argillaceous shales having a light-gray, almost white color, streaked with black and red. The lowest shales exposed are black and friable.

Overlying the light brownish-yellow clay there are in places patches or rolls of a brown sandy loam suitable for molding sand. These patches, however, are not very thick nor of great extent. Their longer axes generally have a north-south direction.

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[a] Most of the notes on the brick clays of Johnson County are by William Kennedy.

The following section shows the relation of the clays and shales of low grounds about Coal Hill:

Section near Coal Hill.

	Feet.
Brown sandy loam	1
Brownish-yellow clay with iron nodules and small sandstone pebbles.	2
Shales with iron-stained streaks	4
Black shales at base.	

No establishments engaged in the manufacture of clay products in Johnson County are at present reported.

LAFAYETTE COUNTY.

Lafayette County lies almost wholly in the alluvial plain of Red River. The geology of these alluvial lands is as a rule less interesting than that of the higher country east and west. There is, however, a strip 6 or 8 miles wide running along the extreme eastern border of the county that has the same geology as Columbia and southern Hempstead counties, and in this region the Tertiary clays are likely to be found. In the vicinity of New Lewisville the cuts along the railroad expose no clay beds that appear to be of importance. Near Bradley station a well put down on the land of H. Smith, in the NW. ¼ sec. 13, T. 19 S., R. 25 W., has the following record:

Section near Bradley station.

	Feet.
Soil and sand	18
Red clay	9
Sand	10

About Walnut Hills are massive beds of red sand, but no clay beds were observed except bright-red ones. In the lowlands along Red River many local pockets of leached pottery clays and extensive beds of good brick clays may be found.

There are no industries of any kind in the county engaged in the manufacture of clay products.

LAWRENCE COUNTY.

GENERAL GEOLOGY.

Black River marks the boundary between the Paleozoic and Quaternary deposits of Lawrence County. The Quaternary area is a level plain having a maximum elevation of about 280 feet and a minimum of about 250 feet.

The streams all flow southwestward, roughly parallel to Black River, and narrow clay flats lie between the streams and the river. The soil adjacent to the streams is of alluvial origin, covering areas from 1 to 3 miles wide on both sides of the streams. The interstream area is a yellow hardpan or clay. In the lower lands the clay has become leached, leaving the surface material a lifeless buckshotty clay land known as "glades." The soil is very poor and but little of it is under cultivation. Water stands on some parts of this land for several months of the year. The character of the strata found at Walnut Ridge is shown in the following well record at that place:

Well record at Walnut Ridge.

	Feet.
Yellow to white clay	16
Fine sand	4
Hardpan similar to surface stratum	6
Fine black sand	5
Red sand, coarse	5
Coarse sand and gravel down to 65 to 70 feet.	

The white clay land extends eastward from Walnut Ridge to Sedgwick, on Cache River. The country to a line within 3 or 4 miles of Cache River, is marked by a rolling surface, with an occasional abandoned water channel.

The following is the general record of the strata in wells at Sedgwick:

General section of wells in Sedgwick.

	Feet.
Soil and clay	3- 6
Hardpan	3- 5
Black sand, water bearing	25-50
Hardpan or clay	2- 3
White sand, water bearing, to 65 feet.	

Just east of Sedgwick there is an area of lowland depressed 6 to 10 feet below the general level, marking the present limits of Cache River bottom, which is about 1 mile wide.

West of Walnut Ridge the country is mostly sandy, except the clay ridge on which Portia is situated, but over all the sandy region the older clay loam appears at the surface in places and forms the subsoil beneath the alluvial sand.

The following is a section of the strata in the east bank of Black River, at Cloverbend, about 9 miles south of Powhatan:

Section in bank of Black River at Cloverbend.

	Feet.
White buckshot clay, very hard when dry	3
Reddish tinted clay, very hard when dry, becoming sandy at base.	3
Reddish stratified sand, rather fine	3
Light-colored gray sand, stratified; coarser than the above	3

The sand is said to extend down to a depth of at least 50 feet below the surface.

The country west of Black River rises 200 feet or more above the bottom lands east of the river. The rocks belong to Cambro-Ordovician series, and are composed of heavy-bedded, dark-colored limestone and of sandstone which is doubtless the equivalent of the St. Peter sandstone in southwest Wisconsin and Missouri.

CLAY INDUSTRY.

In Lawrence County there is but one plant in the Quaternary area that is engaged in the manufacture of clay products. This is Moore & Co.'s brick plant at Walnut Ridge, where common soft-mud bricks are made.

The surface white clay, to a depth of 6 feet, is used for making the bricks. The clay is tempered and molded in a Monarch pug mill, dried in covered racks, and burned in up-draft kilns. It requires three to four days for drying and ten to twelve days for burning. A light fire is kept under the bricks for five to six days, and a hot fire for about the same length of time. Wood is used exclusively for fuel. The bricks are dried and burned without checking. Wheelbarrows are used to convey the green bricks from the molds to the racks and the dried bricks from the racks to the kilns The bricks have a shrinkage of about one-eighth of their volume. The output of the plant is about 1,500,000 bricks per annum. The market for the bricks is Walnut Ridge and the surrounding towns.

There are two common mud-brick plants in the hard-rock district, one at Black Rock and the other at Imboden. The clay used at Black Rock is the yellow or reddish clay, doubtless of the same age as the yellow loam that occurs on top of Crowleys Ridge. The plant at Imboden uses the residual clay of the older rocks.

LEE COUNTY.

GENERAL GEOLOGY.

Lee County is crossed near its center by Crowleys Ridge, which extends in a north-south direction. In the northern part of the county L'Anguille River has cut through Crowleys Ridge and joins St. Francis River about 6 miles southeast of Marianna. North of this L'Anguille River flows in the flat lands on the west side of the ridge and parallel to it. The eastern portion of the county is low bottom land, largely built up of deposits of St. Francis and Mississippi rivers.

The typical calcareous loess forms the top and sides of Crowleys Ridge in Lee County. On the lower slopes on the west side of the ridge there is a kind of terrace or second bottom which is several feet higher than the flat, wet lands farther west. This terrace is very regular in elevation and extends entirely along the foot of the ridge except where it has been cut away by streams. The soil of this second bottom or bench is a light brown or yellow loam, the reworked product of the loess, and is well adapted to the manufacture of bricks.

The country between Marianna and the Lonoke County line is a rolling plain cut into north-south ridges, with low, wooded depressions. The surface of many of these low ridges is a clay loam similar to the surface material on the terrace adjacent to Crowleys Ridge.

CLAY DEPOSITS.

Only one analysis has been made of the surface clays of Lee County, the sample being a reworked product of loess found at the foot of Crowleys Ridge at Marianna. The bricks made from this clay are of a deep-red color, and form a good, strong building brick.

Analysis of reworked loess soil from near Marianna, in sec. 24, T. 2 N., R. 3 E.

[Dried at 110°-115° C. R. N. Brackett, analyst.]

Silica (SiO_2)	75.46
Alumina (Al_2O_3)	10.29
Ferric oxide (Fe_2O_3)	7.07
Lime (CaO)	1.00
Magnesia (MgO)	1.36
Potash (K_2O)	.74
Soda (Na_2O)	.82
Phosphoric acid (P_2O_5)	.30
Loss on ignition	3.18
	100.22
Air-dried sand	72.40

This material is of chocolate-brown color and fills the bottoms and ravines of the region east of Marianna. It seems to be a rearranged and highly ferruginous variety of loess, agreeing with ordinary loess in all other particulars.

CLAY INDUSTRY.

A plant for the manufacture of common building brick was established in Marianna about 1890. It is at present run by O. C. Sutton & Co. The bricks are made from the red surface clay. The clay is tempered and molded in a steam machine having a capacity of 25,000 to 30,000 bricks a day. The bricks are dried by the rack and pallet system, in covered sheds. It requires about seven days to dry the bricks sufficiently for setting in the kilns. Wood is the fuel and the bricks are burned about nine days. Three up-draft clamp kilns are used. About half a cord of wood is consumed in burning a thousand bricks. The size of the bricks is 8¾ by 4⅛ by 2¼.

LOGAN COUNTY.

GENERAL GEOLOGY.

The rocks of the northern half of Logan County belong to the upper coal-producing part of the Carboniferous, while those of the southern half of the county, except the top of Magazine Mountain, lie below the coal. The general geology of the county is like that of Sebastian, Franklin, Johnson, and Pope counties, and the clays and clay shales are very similar to if not identical with those of the counties named.

CLAY DEPOSITS.

CLASSES OF CLAYS.

For convenience of presentation the clays of the county may be classified as follows:

1. Carboniferous clays and clay shales associated with the coal and interbedded with the hard rocks.
2. Buckshot clays or brick loams, found in the uplands.
3. Terrace or second-bottom clays, found along Arkansas River.
4. River-bottom clays of the flood plains of the large streams.

These will be taken up in the order in which they are enumerated.

CARBONIFEROUS CLAYS AND SHALES.

Many of the clays associated with the coal beds of Logan County are fire clays. Some of these beds are only a few inches thick and of limited areal distribution, but it is to be expected that many fire-clay beds of workable thickness will be found associated with the coal. Such clays underlie the coal in the NE. ¼ NE. ¼ sec. 10, T. 7 N., R. 26 W., at the coal opening of H. M. Nichols. This clay is soft, dark blue, streaked with yellow, and only from 6 to 8 inches thick. The miners report that it is not a constant bed. At Wall's slope, in the NE. ¼ NW. ¼ sec. 15, T. 7 N., R. 26 W., a similar clay lies beneath the coal bed, but the mine being full of water, its thickness was not determined.

On the north side of the NW. ¼ NE. ¼ sec. 34, T. 8 N., R. 26 W., two beds of clay are exposed in the channel of a small stream. The upper bed is a dark-brown clay about 3 feet thick; the lower bed is of a lighter yellowish color. Only about a foot of the lower bed is exposed, but it is probably not less than 7 or 8 feet thick. The lower bed is said to have been used as a fire clay. A sample of this lower bed has been analyzed:

Analysis of clay from sec. 34, T. 8 N., R. 26 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	88.66
Alumina (Al_2O_3)	5.73
Ferric oxide (Fe_2O_3)	2.55
Lime (CaO)	Trace.
Magnesia (MgO)	Trace.
Potash and soda (K_2O, Na_2O)	.81
Loss on ignition	2.25
	100.00
Water at 110°-115° C	1.33
Sand in clay dried at 110°-115° C	17.94

Clays of this class are widely distributed over Logan County, and these examples do not fairly represent them either in thickness or importance. The Carboniferous clay shales are so abundant, so thick, and so widespread in Logan County that only a few typical areas will be mentioned.

In the southwest corner of the county the line between Logan and Scott counties crosses Jennings Hill. The alternate series of sandstones and shales forming this hill is described under the heading "Scott County." The same beds extend from Jennings Hill toward Booneville, a distance of 5 miles. The most important shale of this group underlies the town of Belva, in Scott County, but it crosses into Logan County in the NW. ¼ sec. 30, T. 5 N., R. 28 W., runs northeastward for 5 miles, and swings westward along the valley of Petit Jean Creek. This shale is 200 to 400 feet thick at Belva. Below this shale are two beds of sandstone and a thinner bed of shale, followed below by a thicker bed of shale.

A thick deposit of shale near the top of the Atoka formation covers a large area in Logan County and extends also into the adjacent counties both east and west. It ranges in thickness from 400 to nearly or quite 2,000 feet. It is generally of dark color, and although it is usually a clay shale it is at some places sandy. Starting in the southwest corner of the county near Golden City, this shale and its accompanying beds of coal form the surface rock along the upper parts of the valley of Brashy Branch and extend down Fletcher Creek toward the town of Booneville, and thence down the valley of Petit Jean Creek to Magazine. West of Booneville the same shale runs through the northern tier of sections in T. 5 N., R. 28 W., to Barber post-office. East of the town of Magazine the outcrop of this shale divides, one arm of it passing south of Magazine Mountain and underlying the northern part of the northern tier of sections across T. 5 N., R. 25 W., and the southern tier of the township just north of it. The same shale lies along the south base of the range of mountains connecting Magazine Mountain with Mount Nebo in Yell County. Northeast of the town of Magazine these shale beds run northeastward for about 7 miles and then bend abruptly westward to the gap between Brushy Mountain and Calico Mountain. From this point they extend both east and west, with narrower outcrops. The outcrop to the east extends around the north base of Magazine Mountain and then around the base of Huckleberry Mountain, Three Knob Mountain, Spring Mountain, and Mount Nebo. Where the shale beds run around the north sides of the bases of these mountains they are either nearly horizontal or have a gentle southward dip and pass beneath the mountains, to appear again to the south of them. North of the mountains the rocks are folded, passing over an anticline and then dipping northward. The shale therefore appears again north of the anticlinal fold across the entire east-west length of Logan County.

Starting in Yell County northeast of Mount Nebo the same shale underlies Dardanelle Ridge and extends along the south side of its western continuation in Pine Ridge as far as Wildcat Mountain, around which it passes, and runs along the north side of Brushy Mountain until it joins the outcrop in the gap east of Brushy Mountain. Another area of this shale lies between the village of Prairie View and Shoal Creek Ridge, in T. 8 N., R. 24 W. It is only about 5 miles long and less than 2 miles wide. The length of the outcrop of this great body of shale in Logan County thus aggregates fully 150 miles.

In Logan County there is a shale associated with the coal found near Blaine post-office and the village of Shoal Creek and extending thence eastward in Yell County. This same shale horizon runs along the south side of Snake Ridge in T. 8 N., R. 24 W.

The shales in the rolling country at Paris and farther west, to the county line as well as farther east, about Spielersville and Ellsworth, and farther north, to Roseville, belong to an overlying series of rocks associated with the upper coal beds. On the south side of Short Mountain these shales and the coal dip northward and pass completely beneath that mountain, rising to the surface again on the north side. On the sides of Short Mountain thick beds of shales are exposed. The geology of Little Short Mountain is the same as that of Short Mountain. The rocks pass beneath it, so that these two mountains stand in synclinal folds, whose beds are largely composed of clay shales.

It is evident that the Carboniferous clay shales cover an enormous area in Logan County. Unfortunately, no practical tests have been made of these shales, but in so far as the appearance of the materials can be depended upon they are almost everywhere available for the manufacture of paving brick, sewer pipe, and common earthenware, while many of them are true fire clays. With the exception already mentioned (pp. 128–129) no chemical analyses have been made of these clays. The analysis made, however, bears out the theory that the clays are workable, although they are not now utilized.

BUCKSHOT OR PRAIRIE CLAYS.

The clays found in the prairies are chiefly the altered edges of the shale outcrops. These clays have been used for the manufacture of building bricks, but the small iron nodules scattered through them cause the bricks to burn dark brown or spotted. The bricks are almost invariably strong and exceedingly durable, but they have not an attractive color.

In the neighborhood of Paris the clays are principally prairie soils, disintegrated blue shales, and the shales and clays associated with coal beds. Probably the most extensive of the prairie clay deposits is that of Hegwood Prairie. In the E. ½ SE. ¼ sec. 1, T. 7 N., R. 26 W., this prairie soil is yellow, contains a considerable quantity of iron nodules, and has an average depth of 2½ feet. In the NW. ¼ SE. ¼ sec. 1, T. 7 N., R. 26 W., a well 21 feet deep passes through yellow prairie soil 3 feet thick, which rests immediately on blue argillaceous shales of the coal-bearing rocks. In the NE. ¼ sec. 11 and NW. ¼ sec. 12 of the same township and range the yellow soil is somewhat deeper, but its general characteristics are the same. In the SW. ¼ SW. ¼ sec. 6 and the NW. ¼ NW. ¼ sec. 7, T. 7 N., R. 25 W., brick earths of the same yellow color are found, having an average depth of 3 feet. On the road along the south base of Short Mountain and in the SW. ¼ sec. 3, T. 7 N., R. 26 W., the blue shales appear in several places in a ditch on the south side of the road. These shales are 4 feet thick and are completely disintegrated where exposed. Similar clays occur in the valley about Booneville, in the upper bottoms of Sugar Creek, Petit Jean Creek, Revilee Creek, Shoal Creek, and other streams. None of these are utilized in Logan County.

TERRACE CLAYS ALONG ARKANSAS RIVER.

Clays similar to those found in the river terraces near Arkansas River at Fort Smith and at Argenta occur along the south side of Arkansas River in Logan County. These clays are generally sandy and of a reddish color, but wherever they have been tried they have been found available for the manufacture of fairly good building bricks. From Roseville a band of this red sandy clay forming a terrace or second bottom winds about the foothills south of the river bottoms. This terrace is crossed by the Roseville-Paris road just south of Short Mountain Creek. The clay of this terrace is similar to that at Argenta.

Chocolate-colored plastic clays are associated with these terrace clays. Thus far no use has been found for these chocolate clays.

RIVER-BOTTOM CLAYS.

The clays of the Arkansas River bottoms are pockety and of uncertain distribution. They are not likely to be of economic importance, though some of the lenticular masses may occasionally contain pottery clays.

LONOKE COUNTY.

GENERAL GEOLOGY.

Most of Lonoke County lies within the Quaternary area of the State. The country is so flat and unbroken that there are almost no natural exposures of the rocks east of the St. Louis, Iron Mountain and Southern Railway. The extreme northwest corner of the county is in the lower Carboniferous (Mississippian). This includes, however, only the part of the county lying west of the St. Louis, Iron Mountain and Southern Railway, an area of only 55 square miles. The geology in this Paleozoic corner is an eastward continuation of that of Faulkner County. The same beds that outcrop in the southeast corner of Faulkner County pass through the Paleozoic part of Lonoke County to a point where they are overlapped by the Coastal Plain beds near the present location of the St. Louis, Iron Mountain and Southern Railway. The rocks of the lower Carboniferous here consist of alternate beds of sandstone and shales, all of them folded. The ridges through this region are usually of sandstone and run almost due east and west. The shales are parallel with the sandstones and occupy nearly all of the valleys, and in many instances they also form the lower slopes of the ridges.

The Bayou Meto anticline, starting between Preston and Mayflower, in Faulkner County, runs due east toward the town of Austin, Lonoke County, passing through the northern tier of sections of T. 4 N., R. 10 W. North of this anticline as far as Cypress Bayou the rocks all dip northward, and south of it they all dip southward as far as the Cato syncline, which passes through sec. 30, T. 4 N., R. 10 W. These dips of the rocks should be borne in mind in any attempt to utilize the clay shales of this area.

CLAY DEPOSITS.

The clay shales, like those of other parts of the State, vary considerably in character. Some of them are so sandy that it is difficult to determine whether they should be considered clayey sandstones or sandy shales; others contain but little sand, and are sufficiently refractory to be regarded as fire clays. The shales are in places decomposed along their outcrops, but for the most part they are too hard to be pugged as they come from the ground. Analysis of some of these shales shows them to be suitable for the manufacture of paving brick, sewer pipe, fire bricks, or other refractory goods, but they will require to be pulverized.

The character and thickness of these shales, their proximity to the railroad, and the topography of the region are all favorable to the development of important clay industries in this section of Lonoke County.

In addition to the shales there are widespread beds of loam over the slashes or bottoms of Cypress Bayou, Magness Creek, and Wattensas Bayou. The loams are well adapted to the manufacture of common building bricks. In places they contain some buckshot clays, and are therefore not suitable for making high-grade finishing bricks. The bands of buckshot or iron nodules occur here and there at a depth of from 1 to 4 feet from the surface.

The wells at Austin and Cabot penetrate fossiliferous Cretaceous sediments, which outcrop in a few places west of these towns.

What has been said of the Beebe, Kensett, and West Point clays of White County is generally applicable to the clays along the railroad at and near Holland, Cabot, Austin, and Ward.

Two wells near Cabot show the presence of the light-colored clay.

At Neeley & Neeley's gin house in the village of Cabot a well 116 feet deep has the following section:

Section in well at Neeley & Neeley's gin house, Cabot.

	Feet.
Red and sandy clays	39
Calcareous clay (Cretaceous)	1
Marl (Cretaceous)	6
Carboniferous shale to the bottom of the well	70
	116

A well near the center of the NE. ¼ SW. ¼ sec. 25, T. 4 N., R. 10 W., passes through the following beds:

Section in well in sec. 25, T. 4 N., R. 10 W.

	Feet.
Soil	2
Red clay	10
Sandy clay	16
Calcareous clay (Cretaceous)	1
Marl (Cretaceous)	8
Carboniferous shale at bottom.	
	37

The clay here marked "red clay" is mottled red and gray, resembling very closely that underlying the low Quaternary country at different places.

The average well section at Lonoke, as reported by J. C. England, is as follows, the section being that of an open well:

Average section in wells at Lonoke.

	Feet.
Red clay	5–6
White clay grading into sand	5–6
Bluish, mucky, sticky clay.	
Quicksand, all the way from	30–45
Tough clay.	

Wells that reach to a depth of 70 to 80 feet get into gravel. A specimen of this gravel was brought to the office of the Arkansas Survey. It is composed mainly or entirely of waterworn chert pebbles, about the size of a hazelnut, and coarse quartz sand.

The average depth of bored wells at Lonoke is 70 to 85 feet. The deepest well reported is at J. C. England's place and is 107 feet deep.

CLAY INDUSTRY.

Chaplin & England's brickyard.—In the NE. ¼ SW. ¼ sec. 19, T. 2 N., R. 8 W., bricks were once made at the yard of J. P. Chaplin and E. W. England from a mixture of about 18 inches of the top yellowish prairie soil and about the same thickness of a brown iron-stained earth underlying the prairie soil. The bricks are hard and showed a tendency to melt when raised to a high temperature in the kiln. Those that were burned hard have a brown color and are very much spotted with dark, almost black marks. In bricks burned near the center of the kiln the color is a dark cherry red, the spotting is not so prominent, and in many of the bricks the spotting is not visible at all. There was not much loss on account of breaking in the burning. The bricks were machine made.

Harrison Brick Company.—This is the only plant now in operation in the town of Lonoke. It is quite likely, though it is not an assured fact, that this plant is the successor to the Chaplin & England plant. The Harrison plant was established in 1903, and is engaged in the manufacture of common building brick. It has an output of 25,000 bricks a day. The bricks are made from the red surface clay, molded in a steam machine, dried in the open air, and burned in up-draft clamp kilns. When the weather is favorable the bricks will dry sufficiently in three days to stand setting in the kiln. The bricks are burned with wood. About eight days are required to complete the burning. Two kilns are in use, each having a capacity of 175,000.

Wylie's plant.—There is also a brick plant at Cabot, on the St. Louis, Iron Mountain and Southern Railway. It is operated by I. C. Wylie. No further particulars concerning this plant were learned.

MILLER COUNTY.

GENERAL GEOLOGY.

Miller County is entirely within the Tertiary-Quaternary area. The beds everywhere penetrated by wells are Tertiary. Some of them contain marine fossils and others plant remains. Prof. William Moseley, at one time teacher at Texarkana, reports that a fossil palm was found in a well near Texarkana.

CLAY DEPOSITS.

Over the flooded regions of Miller County the soils are in some places alluvial, in others boggy slashes, and in others buckshot clays. The clays of the surface slashes are at many places leached clear of iron by the action of organic acids and carbonic acid, so that these clays are available for the manufacture of the coarser grades of pottery. This leaching, however, is a surface phenomenon, and such clays are nowhere more than 3 or 4 feet deep.

The nature of the surface, with the exceptions just mentioned, has nothing to do with the existence or nonexistence of pottery clays in the stratified beds below. The presence of such beds is seldom indicated by natural agencies in a flat region, where erosion is very slight, so that the existence, thickness, and character of clay beds must usually be determined by testing augers or pits, by digging wells, or by other artificial means.

The higher Tertiary lands about Texarkana occupy T. 15 S., R. 28 W., and a little of the adjoining territory. It is within this area, and principally in the northern tier of sections, that the pottery clays are worked. The occurrence of these clays on the north side of this higher region and the general southeastern dip of the Tertiary rocks of this area suggest that the pits now worked are at or near the northern outcrop of the Tertiary pottery clays and that these same beds dip beneath Texarkana. At what depth they lie beneath that city, however, can be determined only by ascertaining the dip of the strata.

Clay is obtained in a series of small openings in the west side of the SE. ¼ sec. 5, T. 15 S., R. 28 W.

The section exposed is as follows:

Section in sec. 5, T. 15 S., R. 28 W.

	Feet.
Iron-stained sandy clay	3
Whitish blue clay	5
Yellowish sandy clay at bottom.	

The middle bed of 5 feet is a pottery and fire-brick clay. The lower yellow sandy clay was tried for brickmaking purposes, but owing to some defect in the work rather than to the material used the attempt was unsuccessful.

The clay burns to a solid cream-colored body. It admits of both a salt and "Albany slip" glaze. Fire bricks made from this clay are of a light color.

The following are the analyses of these clays:

Analyses of clays from sec. 5, T. 15 S., R. 28 W.

[Sample dried at 110°-115° C.]

	Sandy clay at the bottom.	White clay used for pottery.
Silica (SiO_2)	74.76	75.99
Alumina (Al_2O_3)	13.96	16.12
Ferric oxide (Fe_2O_3)	3.44	1.35
Lime (CaO)	.51	1.45
Magnesia (MgO)	1.10	
Potash (K_2O)	2.28	
Soda (Na_2O)		
Loss (H_2O)	3.95	5.09
	100.00	100.00
Sand in air-dried specimen		.75
Water at 110°-115° C	3.33	1.08

CLAY INDUSTRY.

Kind of clay used.—There are two brick plants and one stoneware pottery in Miller County. The clay used for the manufacture of fire brick and stoneware comes from the Tertiary clays, which are doubtless of the same age as those used at the Benton pottery, situated in sec. 9, T. 15 S., R. 28 W. In one of the pits clay was formerly obtained for the manufacture of stoneware. A sample of clay from this pit was analyzed:

Analysis of clay from sec. 9, T. 15 S., R. 28 W.

Silica (SiO_2)	74.85
Alumina (Al_2O_3)	17.20
Ferric oxide (Fe_2O_3)	1.12
Magnesia (MgO)	1.13
Loss on ignition	5.70
	100.00
Sand in air-dried specimen	3.44
Water at 110°-115° C	1.53

Texarkana Brick Company.—At the plant of the Texarkana Brick Company, established in 1902, dry-pressed bricks are made from a semishale or clay. These bricks are molded in a Boyd dry-press machine and burned in up-draft clamp kilns. Five kilns are in use, each of which is 23 by 59 by 14 feet, inside measurements. Wood and oil are used for burning. The bricks are water-smoked for about ten days without wood and then a hot fire is kept up for about ninety hours. Oil is used for making the hot fire. The size of the green bricks is 8⅞ by 2⅜ by 4¼ inches. The bricks have a shrinkage of about one-sixteenth after burning. The output of the plant is 20,000 bricks a day.

Steven brick plant.—No data have been obtained concerning the brick plant of Anthony W. Stevens, located in Texarkana.

Interstate Pottery Company.—The plant of the Interstate Pottery Company is located at Texarkana. The clay used is the Eocene (Tertiary) clay similar to that used near Benton by the Eagle Pottery Company. Jugs, churns, and jars are made.

MISSISSIPPI COUNTY.

Mississippi County occupies the northeastern corner of the State and is bordered by Mississippi River. The entire county is low and is subject to overflow by the river. The lowest lands are covered with water throughout the year. There are many large lakes in the southern, western, and northern portions of the county. Some of these lakes, such as Big Lake and Tyronza, are several square miles in extent. Levees along the entire Mississippi front are necessary to keep out the flood waters in the spring of the year. The highest land in the county is along Mississippi River, which by repeated overflows has deposited its greatest load on lands nearest the main channel. The westward slope of the country is shown by the fact that many small streams head near Mississippi River and flow westward and drain into Tyronza River and Pemiscot Bayou.

Much of the surface of the county is composed of alluvial deposits of silt, sand, and finely divided clay. In places, however, beneath the alluvial sand there is a yellow clay loam which greatly resembles the yellow clay loam of the prairies west of Crowleys Ridge and the narrow strip of clay land on the east side of the ridge. In a few places the yellow loam forms the surface soil.

At some distance back from the streams and abandoned water courses the country becomes flatter and is now largely covered with water for several months in the year. This land in the interstream areas is a gray buckshotty clay land, covered with a dense growth of sycamore, gum, and cottonwood, with more or less maple, willow, oak, hickory, black oak, elm, and ash. In the buckshotty clay area there are no signs of old stream channels.

At Blytheville there is a brick and tile works plant which makes a common brick from the yellow surface clay loam. The buckshot clay could likewise be tempered with sand and utilized for making common brick.

NEVADA COUNTY.

The geology of Nevada County is like that of Dallas and Ouachita counties, to the east and north, like that of southern Hempstead County, to the west, and like that of Columbia County, to the south.

In Nevada County, however, no large streams cut deep into the soft strata as the Ouachita cuts into those in Ouachita County, so that good exposures of the clay beds are rare and little or nothing is known about them. The strata of this county are nearly horizontal but dip slightly toward the southeast, and therefore a good clay bed found anywhere in the county will probably lie deeper beneath the surface as one follows it southward.

Records should be made of clay beds passed through by wells, for a promising clay found in a well may come to the surface at some point farther northwest. It is not likely that good pottery clays will be found close to the St. Louis, Iron Mountain and Southern Railway, but valuable and abundant brick clays may be found near that road. The best pottery clays and clays available for refractory purposes will be found about the central and southeastern part of the county.

Only one establishment in Nevada County is engaged in the manufacture of clay products, Longston Brothers' common-mud brick plant, located at Emmet, with an office at Sutton.

OUACHITA COUNTY.

GENERAL GEOLOGY.

The geology of Ouachita County may be regarded as typical of the southern portion of the State. The surface is underlain entirely by rocks of Tertiary age except where they have been removed by denudation and the valleys filled with Quaternary alluvium or residuary accumulations. The Tertiary rocks are usually not very hard; they are clays, sands, lignites, and gravels, and these four at many places grade into one another, forming sandy clays, clayey sands, lignitic clays, and all other possible combinations. At some places the sands are indurated, forming hard quartzites; at others they are but loose sands; while in color they range through the browns, yellows, grays, and reds.

Though local dips may be seen, most of the rocks lie in horizontal or approximately horizontal beds, so that they may readily be traced from one locality to another.

The Tertiary beds have been cut by Ouachita River, which has washed out a wide valley. This valley is bordered on the west by a rather abrupt escarpment, in which the Tertiary beds outcrop, especially at points where the river hugs its right bank, as at Camden, Newport Landing, and Millers Bluff.

In Camden a steep-sided ravine having walls 40 feet high is cut in the soft sandy clays by the stream.[a] A large part of the exposed surface of these clays was at one time covered with an abundant scence of green vitriol (ferrous sulphate) derived from the This green vitriol causes the peculiar taste of the water found f the wells at Camden.

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[a] The section exposed on the Ouachita at Camden is given in Ann. Rept. Geol Survey Arkansas for 1888, vol. 2, p. 50.

racter and disposition of the Tertiary beds at Camden aken in a certain sense as typical of the geology of Ouachita The strata there exposed extend beneath the whole county, n a more or less modified form. This variability of the strata errupts, of course, the continuity of the clay deposits and of whatver else there may be of economic value in these beds. The sandy clays, for example, in their horizontal distribution give place to pottery clays, and pottery clays give place to brown coal, and brown coal gives place again to clays or sands or some of the other beds so common throughout the county.

In some places the beds are deeply eroded and broad valleys are formed in them, so that the strata for several miles have been washed away, clays, sands, coals,[a] and all. The valley of the Ouachita is itself an example of such erosion. The road from Lester station, on the Camden branch of the St. Louis, Iron Mountain and Southern Railway, to Camden passes over a sharp ridge called Seely Mountain, which rises about 200 feet above the level of the Ouachita bottoms. About 4 miles northwest of Camden the same road ascends Parker Hill, which is geologically a repetition of Seely Mountain and which has the same elevation, the two being separated by a broad valley which has been cut out by the ordinary process of erosion. The profile section in fig. 12 will make plain the relations of these ridges to each other.

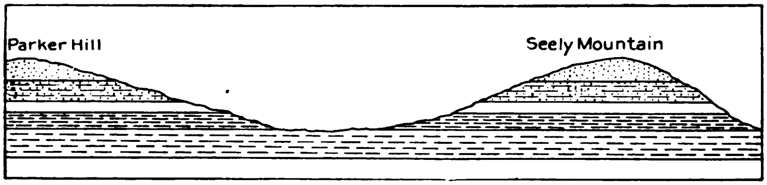

FIG. 12.—Section of Parker Hill and Seely Mountain, Ouachita County.

These details of general structure are given for the purpose of showing how the distribution of clays in Ouachita County is determined by the geology of the region.

CLAY DEPOSITS.

The region in which the brown coals occur is a promising one in which to seek valuable clays both for the manufacture of pottery and for fire clays.

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[a] The Geological Survey of the State has data for a report on the coals of Ouachita County, and the United States Geological Survey has published a report on this subject by Mr. Joseph A. Taff in Twenty-first Ann. Rept., pt. 2, 1900, pp. 319–329.

In the S. ½ SE. ¼ sec. 2, T. 12 S., R. 18 W., on a small stream called Sandy Branch, is an exposure of material that has received considerable attention. It has the appearance of being a very sandy, compact, nonplastic, whitish cream-colored clay. It has usually been regarded as a fire clay, but the percentage of water of crystallization contained in the material when freed from sand shows it to be a kind of kaolin.

This bed is exposed inconspicuously at three or four places on Sandy Branch, at the base of the hills that form the western limit of the immediate valley of Ouachita River. Most of the outcrop is concealed by débris that has fallen down from the hills above, but it has been opened sufficiently to show its relation to the overlying beds and to expose a thickness down to the water of Sandy Branch of 12 feet, but without discovering the total thickness of the deposit.

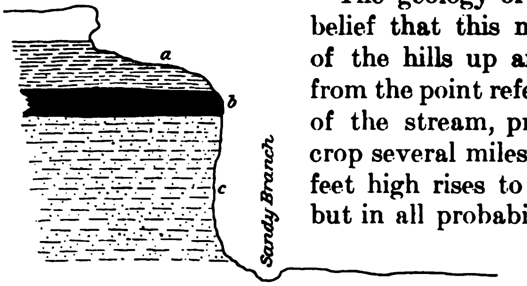

FIG. 13.—Section on Sandy Branch, near Ouachita River, Ouachita County. *a*, Plastic clay; *b*, brown lignite; *c*, sandy kaolin.

The geology of the region leads to the belief that this material lies at the base of the hills up and down Sandy Branch from the point referred to and on both sides of the stream, probably forming an outcrop several miles long. A hill nearly 100 feet high rises to the west of the outcrop, but in all probability places may be found at which there is no considerable covering to the bed. At the exposure referred to a bed of brown lignite[a] about 3 feet thick overlies the clay, and above this is a bed of plastic clay, the thickness of which is not exposed.

Fig. 13 is a section at this locality.

The following is an analysis made by the St. Louis Sampling and Testing Works of a sample said to have been taken from this kaolin bed. It was kindly furnished by Dr. A. S. Garnett, of Hot Springs, who had the analysis made in August, 1889:

Analysis of kaolin from Sandy Branch.

Silica (SiO_2)	66.25
Alumina (Al_2O_3)	25.35
Sesquioxide of iron (Fe_2O_3)	.22
Lime (CaO)	.26
Magnesia (MgO)	Trace.
Alkalies	.84
Water and loss	7.32
	100.24

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[a] As a rule this lignite is considerably thinner on the outcrop than inside.

The following is an analysis of a sample of material said to have come from "Red Hill," made in 1882 for Walter Hamilton, of 120 William street, New York City, by A. Guyard, chemist. The material seems to be the same as that found in the Sandy Branch exposure.

Analysis of kaolin from Red Hill.

Silica (SiO_2)	70.40
Alumina (Al_2O_3)	18.40
Peroxide of iron (Fe_2O_3)	1.25
Titanic acid (TiO_2)	.05
Manganese (MnO)	Trace.
Lime (CaO)	.55
Magnesia (MgO)	.25
Alkalies	Trace.
Sulphuric acid (H_2SO_4)	.25
Water (H_2O)	8.75
Loss	.10
	100.00

A sample collected by the State Geological Survey of Arkansas (through Arthur Winslow, assistant geologist) at the Sandy Branch locality was analyzed by the Arkansas Survey. The label with this specimen says it comes from the NW. ¼ SW. ¼ sec. 2, T. 12 S., R. 18 W. Whether it came from that locality or from the one on Sandy Branch, the material is the same.

Analysis of kaolin from sec. 2, T. 12 S., R. 18 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	76.21
Alumina (Al_2O_3)	16.00
Ferric oxide (Fe_2O_3)	.75
Lime (CaO)	Slight trace.
Manganese and alkalies (by difference)	1.06
Water on ignition (H_2O)	5.98
	100.00

Anyone examining this material is impressed by the fact that it contains a large percentage of sand, though, of course, samples can be selected that are comparatively free from sand. In order to determine the nature of the material when freed from the greater part of the coarse sand, a sample of it was washed. The following is the analysis of a sample of the washed material, the sand being deducted from the silica and the composition recalculated:

Analysis of washed kaolin from sec. 2, T. 12 S., R. 18 W.

Silica (SiO_2)	28.47
Alumina (Al_2O_3)	48.00
Ferric oxide (Fe_2O_3)	2.25
Magnesia (MgO) Alkalies	3.18
Water (H_2O)	17.84
	99.84

This shows that this material is simply a sandy kaolin and not an ordinary clay, in the chemical sense of that term.

After the sand is removed by washing it is available for the manufacture of pottery and also as a refractory material. As a fire clay it will be spoken of elsewhere in this report. The quantity of this kaolin in the vicinity of the locality described above seems to be very large. Mr. Winslow observed the following section in the NE. ¼ SW. ¼ sec. 2, T. 12 S., R. 18 W., under a bluff very like that observed by the writer on Sandy Branch:

Section in sec. 2, T. 12 S., R. 18 W.

	Ft.	In.
Sand and clay	6	
Decomposed lignite		8
Gray clay	1	6
Decomposed lignite	1	6
Sandy kaolin	12–15	

At this place also the full thickness of the bed is not seen.

It is reported from several places in sec. 36, T. 11 S., R. 18 W. At one point the former exposure is said to have recently been concealed by a landslide; at another place it is said to be 4 feet thick, and has been used for whitewash.

In the SW. ¼ NW. ¼ sec. 36, T. 11 S., R. 18 W., at the house of Jack McKinzie, the following section was passed through in digging a well:

Section in well in sec. 36, T. 11 S., R. 18 W.

	Feet.
Clay	2
Lignite	2½
Gray clay with sand	3+

There are thin beds of pottery clay on a branch of Wolf Creek at the mouth of a lignite drift in the NE. ¼ NW. ¼ sec. 14, T. 12 S., R. 18 W. These beds are only a few inches thick, and therefore too thin to be of any practical value. Inside the drift they are only 6 or 8 inches thick. It is possible that these beds may be thick enough in this neighborhood to render them valuable. The clay itself is of fair quality, as the following analysis of it shows:

Analysis of clay from NE. ¼ NW. ¼ sec. 14, T. 12 S., R. 18 W.

[Sample dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	79.42
Alumina (Al_2O_3)	13.35
Ferric oxide (Fe_2O_3)	2.17
Lime (CaO)	Trace.
Magnesia (MgO) Potash (K_2O) Soda (Na_2O)	Trace.
Loss on ignition (H_2O)	5.38
	100.32
Sand in air-dried specimen	9.48
Water at 110°-115° C	3.72

In burning, this clay becomes a light gray and loses 9.68 per cent of its weight.

The following is the section exposed at the Sulphur Spring coal drift, at the base of the hill near the house of the superintendent of the Ouachita Coal Company's mines.

Section at Sulphur Spring coal drift.

	Ft.	in.
1. Yellow sand	15	
2. Thinly laminated sands and clay	7	
3. Sand		2
4. Buff pottery clay	1	6
5. Lignite	5	
6. Clay with fossil leaves	6+	

No. 2 of the above section is made up of interstratified half-inch beds of sand and pure clay, with fragments of vegetation scattered through them, in which form it can not be utilized. No. 4 is a good clay and might be utilized if the bed were thicker. Near the mouth of the drift it is somewhat stained with iron, but will not be found so stained farther in the hill. No. 6 is said to have been penetrated 6 feet in digging a sump in the coal mine, but at this depth it was not passed through. The leaf impressions in this clay are very abundant and fresh.

Mr. Winslow reports the following section from the old mine half a mile from the Ouachita River, in the NW. ¼ NE. ¼ sec. 12, T. 12 S., R. 18 W.

Section in old mine in NW. ¼ NE. ¼ sec. 12, T. 12 S., R. 18 W.

	Ft.	in.
Sand on surface.		
1. White sandy clay	3	
2. Chocolate sandy pottery clay	3	
3. Yellow and white sand	8	
4. Bluish-gray clay with sandy seams	8	
5. Carbonaceous shale		6
6. Lignite	5–6	
7. Gray clay not penetrated at	3	

No. 2 of the above section is a massive chocolate-colored clay that does not crack on drying. It seems to be available for the manufacture of both pottery and fire bricks. No. 7 is a tenacious pottery clay containing an abundance of well-preserved impressions of leaves. This bed strongly resembles the lower leaf-bearing bed of Atchison's pits at Perla switch, Hot Spring County, used for the manufacture of fire bricks.

The clays mentioned in this section are not being utilized for any purpose, although a company is said to have under consideration the question of erecting brick and sewer-pipe works in the neighborhood.

Mr. Kennedy reports also that at drift No. 1 on the Beach tract, within 200 feet of the county road, under the brow of a sandy hill, in the NE. ¼ NW. ¼ sec. 29, T. 12 S., R. 18 W., there is a bed of pottery clay about 2 feet thick overlying the lignite. The upper 6 inches of this clay is of a yellowish color; the lower 18 inches is bluish gray. Both portions contain a large amount of very fine micaceous sand. The gray portion seems to be a fair potter's clay.

Wells bored at Henry C. Bell's place on sec. 4, T. 13 S., R. 18 W., passed through an aggregate of 17 feet of clay and 4½ feet of lignite. The order of their arrangement could not be ascertained.

A well put down at Wilson Carter's gin in the NW. ¼ NW. ¼ sec. 15, T. 12 S., R. 19 W., has the following section:

Section in well at Wilson Carter's gin.

	Feet.
Sand	15
Clay	5
Lignite	4½
Clay.	

Mr. Kennedy reports a drift in the NW. ¼ NW. ¼ sec. 15, T. 12 S., R. 18 W., with 3 feet of blue-gray clay above and below a 3-foot lignite bed.

Near Dempay's mill, in the S. ½ SW. ¼ sec. 25, T. 12 S., R. 18 W., the road descending from the hills to the flood plain of Ecore Fabre Creek passes over some light-gray sandy clays that appear to be available for pottery. From this point the highlands that border the right side of the Ouachita Valley follow a zigzag course through secs. 25, 24, 13, 12, 11, 1, and 2 of T. 12 S., R. 18 W., and still farther north it passes through secs. 36, 35, 25, 26, 34, and 33, T. 11 S., R. 18 W., and returns to secs. 4 and 5 of T. 12 S., R. 18 W. The clay outcrops follow in and out around the sides of these hills, though as a rule they are concealed by the earth and humus that have accumulated upon them. Outcrops of the same beds may be traced in the same way about the headwaters of Wolf Creek and of Ecore Fabre Creek.

South of Ecore Fabre Creek the Lester-Camden road rises to higher ground in the NW. ¼ NW. ¼ sec. 1, T. 13 S., R. 18 W. In these higher lands good pottery clays crop out locally in gullies and in the bluffs, but for the most part the outcrops are concealed by débris from the overlying beds. In the SW. ¼ NW. ¼ sec. 1, near Joshua Lester's house, this clay is exposed on the hillside just west of the road. The section shows 2 or 3 feet of sandy clay with 2 feet (exposed) of pink sandy potter's clay beneath it. This clay contains fossil leaves.

Mr. Lester's house is in the NE. ¼ SW. ¼ sec. 1, T. 13 S., R. 18 W. Just across the road west of his house, and about 200 feet from it, there is a 3-foot bed exposed; above it the soil is streaked with red, and contains thin bands of limonite; below it are red sandy clays, over 15 feet of which are exposed.

The sections exposed in Seely Mountain and in Parkers Hill, south of Lester, on the road to Camden, show very sandy beds, with no available pottery clays. These clays appear to lie at a lower level, and to wind in and out about the hills toward their bases.

In the city of Camden there is a small pockety bed of pottery clay, in places 3 feet thick, on the west side of the Missouri Pacific Railway, on California street.

The Arkansas Company, an organization with an office at Lester, Ark., owns a large part of the lignite and clay lands between the Camden branch of the St. Louis, Iron Mountain and Southern Railway and Ouachita River in T. 12 S., R. 18 W. This company put down a deep well at the center of sec. 12 of that township and range. Dr. A. S. Garnett, of Hot Springs, Ark., kindly furnished a copy of the record of this well, which shows the various clay beds and their thicknesses.

Record of well at the center of sec. 12, T. 12 S., R. 18 W.

	Feet.
Common clay	25
Blue fire clay	15
Coal (lignite)	5
Fire clay	15
Quicksand	60
Decomposed clay	5
Sand	30
Hard clay	30
Coal (lignite)	5
Hard clay	15
Sandy clay	110
Coal (lignite)	5
Sand and clay	50
Quicksand	100
Sand and clay	75
Hard clay	15
Coal (lignite)	10
Clay and sand	50
Coal (lignite)	2
Quicksand	175
Rock and sand	55
Total depth of well	852

From what has been said of the exposures known, it will be seen that pottery clays are to be looked for in the lower portions of the hills that skirt the Ouachita Valley. The steepness of these hills on the west side of the river gives rise to a great number of natural exposures of the clay beds, but the same beds may confidently be looked for on the east side of the river and in the gentler slopes of that side of the valley, though they are there farther from the stream.

It is noticeable also that good clays are at some places associated with the Tertiary coals or lignites of this region. Thus the lignite, which usually attracts attention more readily than clays, serves to a certain extent as a guide in searching for valuable clays.

CLAY INDUSTRY.

Notwithstanding the fact that Ouachita County is remarkably well supplied with potter's clays, no clay industry is known to exist in the county at the present time, and the only plant that has existed, and of which information could be had, was a pottery located about 8 miles south of Camden and about 2 miles from Ouachita River, on the farm now belonging to Mr. Thomas Patton (Camden post-office). The clay is said to have come from one of the stratified beds of the hillside. The pottery has not been in operation since the breaking out of the civil war.

PHILLIPS COUNTY.

GENERAL GEOLOGY.

The southern half of Phillips County is covered by the alluvial deposits of Mississippi and White rivers. The northern half is broken by Crowleys Ridge, which has its southern terminus at Helena, on Mississippi River. West of the ridge is a series of much lower ridges, or low swells, which have a general north and south direction. These smaller ridges are broken by streams and intervening depressions.

The elevation of the lowlands in the southern portion of the county is but a few feet above the water in Mississippi River. The elevation of the depot at Helena is 194 feet above sea level. The highest point on the top of the ridge at Helena is 198.9 feet above the zero gage. The elevation of the zero gage is 148.85 feet above sea level. The top of the ridge is therefore 347.75 feet above sea level, and about 150 feet above the lowlands to the west.

The bluffs along the south end of the ridge in the vicinity of Helena give good exposures of Tertiary and Quaternary strata. The loess covers the top and sides of the ridge here as at most places throughout the State. The rearranged product of the loess covers the older underlying strata, which are seen at only a few places.

At the west end of Cherry street in Helena, and along the bluff to the south, there is a bed of iron-stained pebbles, which greatly resemble the pebbles of the Lafayette formation. The top of the pebble bed stands at an elevation of 205 feet. Immediately above the bed of pebbles comes about 10 feet or more of orange-colored loam. Overlying the loam is an apparent soil zone, having a maximum thickness of 10 feet. This is present in many places, but it is at others absent. The remaining part of the bluff is composed of typical calcareous loess, containing numerous land shells.

In places where recent excavations have been made the loess is distinctly stratified. Viewed from a distance it has a general stratified appearance, but when more closely inspected many more faint lines of stratification can be seen.

At the big spring 2 miles north of Helena, on the east side of the ridge, 80 feet of variegated sands, clays, and lignitic clays are exposed in the deep ravine just north of the spring. The iron-colored pebbles and overlying orange-colored loam, seen at the foot of the bluff on Cherry street in Helena, comes above the 80-foot section of variegated sands and clays at this spring. The top of the bluff is covered with loess.

Along the western edge of Crowleys Ridge in this county there is an apparent terrace from one-half to 3 miles wide. It has a uniform elevation 20 to 30 feet higher than the plain to the west.

A section in a gulley 1½ miles east of Southland shows strata of the character found in the terrace west of the main ridge.

Section of terrace 1½ miles east of Southland.

	Feet.
Stratified dark clayey loam	4
Thin, laminated, argillaceous sand, with small, irregular concretions of iron oxide	4
Yellow argillaceous sand	2

CLAY DEPOSITS AND INDUSTRY.

The principal brick clays of Phillips County are the loess and rearranged loess found on the top and sides and at the foot of Crowleys Ridge. Bricks could be made from the upper loam of the terrace along the west side of the ridge and also from the clays that form the surface of Pine and Hickory ridges. So far, however, the brick industry of the county is limited to the city of Helena.

The plant of the Straub Brick Company is located on the southwest side of the town, at the foot of Crowleys Ridge. The capacity of the plant is 36,000 bricks a day. The bricks are made from the loess, which has been slightly reworked and mixed with the underlying clays. It requires a greater amount of care to make good bricks from this clay than from ordinary clay. The loess is a very fine, silty, calcareous loam, lacking plasticity, and it is very easy to get too much water in the pug mill. It is found to be more profitable to make soft-mud brick in the summer, and dry-pressed brick in the fall and winter.

The bricks are dried in the open air by the pallet and rack system. Most of them are burned in up-draft kilns. Only one down-draft kiln is used.

PIKE COUNTY.

GENERAL GEOLOGY.

The geologic age and character of the deposits in the southern part of Pike County encourage the hope that valuable beds of kaolin exist there. These beds, however, must be sought within the Mesozoic area and not in the region of hard Paleozoic rocks to the north.

In a general way the northern border of the Mesozoic rocks in Pike County passes from Antoine just north of Wolf Creek post-office, Brocktown, and Murfreesboro, and south of Royalston, passing into Howard County where the county line crosses Muddy Fork of Little River. North of this line it is useless to look for kaolin in commercial quantities in Pike County.[a]

CLAY DEPOSITS.

It has been known for several years that kaolin exists in Pike County, but the only plant of any kind in the county that is engaged in the manufacture of clay products is a small brick plant at Nathan.

Some fine specimens of kaolin were exhibited at the exposition held at Little Rock in the summer of 1887. These specimens were labeled "Pulaski County," but they must have come from the Vaughn Creek beds, in Pike County. At least no such kaolin is known in Pulaski County.[b]

The kaolin beds of Vaughn Creek have been examined by the State Geological Survey at the pits opened in the NW. ¼ SW. ¼ sec. 19, T. 8 S., R. 24 W., near S. D. Hanna's house. The locality is known in the surrounding country as "the chalk bank." Its discovery seems to have been due to the fact that pieces of kaolin were torn out by an uprooted tree. The material has been used to some extent through the country for school chalk.

The kaolin lies in horizontal beds in the tops of the hills that skirt the right bank of Vaughn Creek. These hills are low and are covered with an abundance of waterworn pebbles and cobblestones of Pleistocene age. In the valley of Vaughn Creek, about 75 feet below the summit of the kaolin-bearing ridges, lignites of the Trinity beds (lower Cretaceous) have been found in digging a well at Mr. S. D. Hanna's, in the SE. ¼ NW. ¼ sec. 19, T. 8 S., R. 24 W. The stratigraphic position of the koalin would admit of its belonging either to the lower Cretaceous, the upper Cretaceous, or to the Tertiary. In the absence of other evidence it is therefore impossible to say to which of these horizons it belongs. It is believed that the beds are of Cretaceous age, but this can not be stated as anything more than an opinion based on observations of the topography and stratigraphy of the Cretaceous beds farther west and south.

The accompanying section (fig. 14) is exposed in one of the old prospecting pits dug on the kaolin. It is impossible to say whether this kaolin bed represents the full thickness of the deposit in Pike County. A few other smaller holes have been dug in the immediate vicinity, but as they are all within 100 feet of this one and were dug to strike the same deposits, they throw no light on the nature of the beds except at this one place.

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[a] The Mesozoic rocks of Pike County are shown on the map of that region accompanying vol. 2 of the report of the Geological Survey of Arkansas for 1888.

[b] In 1890 these specimens, still labeled "Pulaski County," were on exhibition at the rooms of the State Department of Agriculture at Little Rock.

The broken bed *cl* of the section appears to be the remains of a bed of kaolin from which a part of the constituents has been removed by decomposition. The larger fragments, when broken parallel with the bedding, show a great many obscure and small plant impressions, resembling those made by blades of grass. None of the forms seen are recognizable, however. The upper part of the bed marked *ka* in the accompanying section contains a little grit in the form of grains of fine quartz sand. It also shows a great many indistinct and fragmentary impressions of plants. These plant impressions are very small and none of those found are determinable. The lower part of the bed *ka* is pink in color, and contains besides many small white spots about the size of a pin's head. These spots are kaolin like the rest, and retain their white color, distinct from that of the rest of the material, even after firing and glazing.

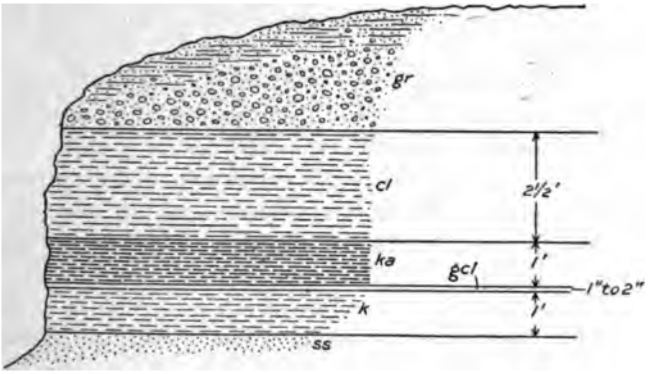

FIG. 14.—Section of kaolin deposits on Vaughn Creek, Pike County. *gr*, Lafayette gravel; *cl*, impure clay; *ka*, pink kaolin with white specks; *gcl*, granular, white streak of clay; *k*, white kaolin, iron-stained joints; *ss*, yellow sand.

In sec. 19, T. 8 S., R. 24 W., and in sec. 24, T. 8 S., R. 25 W., the following record of the order of the beds is reported by Mr. E. C. Buchanan, of Little Rock:

Section in secs. 19 and 24, T. 8 S., Rs. 24 and 25 W.

	Ft.	In.
Earth and gravel	2	3
Kaolin with sand and red streaks		6
Kaolin and sand	1	6
Kaolin with streaks	1	6
Pinkish sand	1	8

Other pits show the same order, but in some of them the clean kaolin is thicker.

Mr. Buchanan, after having spent some time in examining the kaolin deposits of Pike County, wrote the following general conclusions regarding them:

> The beds are from 3 to 9 feet in thickness and are very variable in color. Shafts only a hundred feet apart exhibit considerable differences in the sections. The following is a typical section as near as such a section is possible:

Typical section in Pike County.

	Feet.
Sand and gravel	3–25
Sand varying in color, but generally reddish or pink, with thin sheets of iron oxide	4
Kaolin, solid, pale yellow to white, with red or yellow streaks	3– 9
Sand	3+

The colors found in one shaft were not always the same as those in an adjacent one. The largest area of kaolin found in one body covered about 10 acres. The greatest depth at which the kaolin was found was 25 feet.

So far as these deposits have been examined they appear to be rather lens-shaped beds of limited distribution. Some of these beds cover only half an acre; others cover an area of 8 or 10 acres. Mr. Buchanan is of the opinion that the entire kaolin area probably does not exceed 350 acres. These lands lie in secs. 19 and 30, T. 8 S., R. 23 W., and in secs. 23, 24, 25, and 26, and probably in secs. 35 and 36, T. 8 S., R. 24 W.

The more massive beds of kaolin contain no evidence of its derivation beyond its sedimentary origin. The kaolin contains, as one might expect, fragments of quartz, but not enough to affect the value of the material for economic purposes. It has a conchoidal fracture, but within the stratum there are no bedding or lamination planes. In the beds above and below it there are evidences that the accompanying strata were deposited in water, a bed of sand underlying and a bed of less pure kaolin overlying it. There can be no doubt, therefore, of the sedimentary origin of the Pike County kaolin.

It is worthy of mention that no exposures of feldspathic rocks are known anywhere in this neighborhood. The nearest large exposure is at Magnet Cove in Hot Spring County, 50 miles distant, but as the Pike County kaolin is Cretaceous it can have no genetic relation to the Magnet Cove rocks, for the latter are probably of post-Cretaceous age; certainly they are not pre-Cretaceous, and could not therefore have supplied the material for this kaolin.

The Pike County kaolin is different in physical characters from any other kaolin thus far found in the State. It is not plastic in its natural condition, but has a hardness of about 1.5 in the mineralogical scale, being easily scratched with the nail. When dry it adheres strongly to the tongue, but it can not absorb enough water to render it plastic, even when left submerged for weeks. In the pit, where it is thoroughly soaked with water, it is brittle and breaks with a splintery conchoidal fracture. When dry and rubbed with the hand it takes on a satin-like gloss. Ground to a fine powder and wet, it forms a nonplastic or but partially plastic mass.

A sample of this kaolin that had been left to air dry for several months and then submerged in water cracked to small angular pieces with plainly audible snapping sounds, very much as if it had been a piece of hot glass. Within five minutes the breaking had ceased, and though the kaolin remained in water for several days, it showed no further signs of being affected by it.

The fact that this kaolin does not soften in water like clay is a disadvantage, for it would need to be ground and washed before it could be used in the manufacture of fine pottery. A sample of it has been put to a practical test by being fired and glazed in one of the New Jersey potteries. It stood this test in a very satisfactory manner.

Below are given analyses of both the upper pink and the lower white kaolin of the section given on page 149. The locality is in the NW. ¼ SW. ¼ sec. 19, T. 8 S., R. 24 W. These analyses may be compared with those of well-known kaolins in the table on pages 236–237.

Analyses of kaolins from Vaughn Creek.

[Dr. T. C. Van Nuys, analyst.]

	Upper bed.	Lower bed.
Silica (SiO_2)	48.87	47.39
Alumina (Al_2O_3)	36.51	34.67
Iron (ferric) oxide (Fe_2O_3)	.98	2.31
Lime (CaO)	.19	.32
Magnesia (MgO)	.25	Trace.
Potash (K_2O)		.20
Soda (Na_2O)		.39
Water	13.29	13.89
	100.11	97.17
Water at 110°-115° C		1.00

At the pit from which the sample of the lower bed was taken the kaolin is much fractured, and iron-charged waters have infiltrated along these fracture lines and stained them a deep brown color, though the material still holds together compactly. When a mass removed from the bed is struck hard, it breaks along these fractures. The iron stain seriously injures the kaolin, probably rendering it worthless for fine ware. It is evident, however, that the iron has been leached from the waterworn gravels, sands, and clays that cover the surface of the ground and has been redeposited in the only part of the kaolin it could easily penetrate—that is, along these crevices. If, therefore, kaolin available for the manufacture of the finer grades of porcelain exists in commercial quantities in the neighborhood of the Vaughn Creek pits, it should be looked for at places where it will have a covering thick enough to protect it from infiltration of iron-charged waters from the surface.

The analyses of this kaolin show that except for the stains referred to above it is sufficiently pure for the manufacture of fine porcelain ware. It seems to be well adapted also for paper finishing. It also has high refractory properties, and in case it can not be found free from the impurities that would injure it as a china clay, it is still available for the manufacture of a high grade of fireproof articles.

Prospecting for kaolin that lies in horizontally stratified beds, as do these of Pike County, is a very simple matter and will not be expensive unless one happens upon thick deposits of the Pleistocene waterworn material that covers the surface of the ground. The accompanying diagram (fig. 15) is intended to show the method of occurrence of the kaolin with reference to the waterworn gravels of that region.

A vertical section cut through these beds would show that they have some such relations as those indicated in the diagram. The kaolin lies in a horizontal bed, *ka*, and the sands, *ss*, clays, *cl*, etc., associated with it, are also horizontally bedded. These beds have been worn away from above and the great body of kaolin originally deposited has been removed. What remains is fragmentary and, in the vicinity of the Vaughn Creek pits, at least, lies in the hilltops, but over the worn surface gravel beds, *gr*, have been spread out, covering the greater part of the surrounding country. This gravel varies greatly in thickness. At some places it is almost entirely wanting or is represented by only a few pebbles, while at others it has a thickness of 30 feet or more. It is at many places impossible to foresee the thickness of this gravel covering, for, as will be realized from the diagram, the thickness at *a* would give a miner no clue whatever to the thickness of the same deposit at *b*, and vice versa.

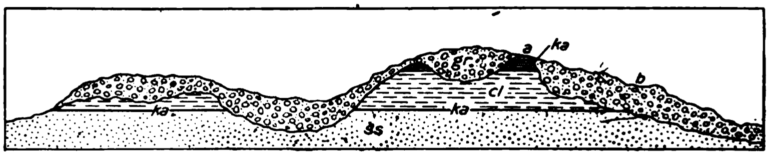

FIG. 15.—Section of kaolin beds in Pike County.

The horizontality of the kaolin beds makes prospecting for them simple and cheap. It is only necessary to ascertain the elevation on the hillside at which the bed is to be exposed, judging from the elevation at which it occurs at known localities, and then to dig a trench up and down the face of the hill so as to crosscut the bed. This trench should pass entirely through the waterworn gravels and uncover the underlying beds. If the kaolin bed were perfectly horizontal such a trench would not be necessary, for a pit could be opened directly on the bed, but its position varies somewhat, and this variation makes the trench necessary.

It will be seen from the foregoing that whether or not considerable quantities of kaolin are to be expected in the region west of Vaughn Creek in Pike County depends on the topography of the country. If the hills are all lower than the point at which the outcrop is found, near Mr. Hanna's, the kaolin has all been washed away. If the hills are higher and their height is not due to the great thickness of the gravel bed, the kaolin may reasonably be expected to outcrop on the hillsides. In broad and flat-topped hills, with kaolin outcropping around the margins, prospecting may be done by boring with testing augers on the hilltop. If the boring is in a depression it will not be necessary to bore through so great a thickness.

There is a very widespread and a very erroneous impression among a certain class of miners that mineral deposits grow thicker and better as one goes deeper. In the case of this kaolin, other things remaining the same, the material will improve as the cover thickens, but this is simply because the thicker cover prevents the infiltration of iron into the kaolin. Whether the beds thicken or not can not be predicted, but in view of the sedimentary origin of the deposit it is reasonable to suppose that they will not vary greatly in thickness.

In the SW. ¼ NE. ¼ sec. 24, T. 9 S., R. 24 W., a bed of kaolin is said to have been discovered in digging a grave about the year 1874. This point is said to be on the top of a sandy hill or bench about 30 feet above the "bottoms" of Little Missouri River.

POINSETT COUNTY.

GENERAL GEOLOGY.

The topography of Poinsett County is very similar to that of Cross County on the south and Craighead on the north. The eastern half of the county is a low, flat country, which is traversed by St. Francis River. A large area in the northeastern part is covered by shallow lakes, which were caused by the general sinking of the land during the earthquake period of 1811-12. Crowleys Ridge extends across the county in a north-south direction just west of the center. The country west of the ridge is a flat slash land sloping to the south and west. The elevations along the St. Louis, Iron Mountain and Southwestern Railway, in the western part of the county, are from 7 to 24 feet higher than corresponding points in the same latitude along the St. Louis and San Francisco Railroad in the eastern part of the county.

The Tertiary sands and clays outcrop in deep ravines and in roads along the sides of Crowleys Ridge, in the vicinity of Harrisburg, and doubtless at other places on the east side of the ridge. The top of the ridge at Harrisburg is 107 feet (barometric reading) above the elevation of the town at the foot of the ridge. The following is a section of the hill along the road leading east from the town:

Section of Crowleys Ridge at Harrisburg.

	Feet.
Yellow clay (Columbia) on top of ridge	30
Stratified sand, variegated in color, interbedded with gray joint plastic clay	65
Unexposed detritus to foot of hill	12

A record of one of the wells in the town at the foot of the ridge gives the following section:

Section of well in town of Harrisburg.

	Feet.
Red to yellow clay, with some gravel	40
Blue gumbo clay free from sand, with small vein of water on top	25
Very fine red dry sand, which caves badly	40
Dark-blue or slate-colored sandy clay, containing small fragments of leaves, shells, and rotten wood; gives bad odor to water	50
Blue sand, water bearing	30

CLAY DEPOSITS.

The surface clay, which is 40 to 50 feet thick at foot of the ridge at Harrisburg, is only about 10 feet thick at L'Anguille River, 4 miles west of town. It changes from a reddish yellow at the foot of the ridge to white at L'Anguille River. In places it forms buckshot soil.

The surface yellow clay on the top and sides of the ridge, and also the surface clay in the lowlands as far west of L'Anguille River, are well suited to the manufacture of common wet or stiff-mud and dry-pressed bricks. The blue Tertiary clay that outcrops well up on the side of the ridge would, with proper manipulation, doubtless make an excellent face brick. The following analyses are made from brick clay at Harrisburg, Poinsett County:

Analysis of brick earth from the surface, Harrisburg.

[Dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	81.79
Alumina (Al_2O_3)	9.37
Iron oxide (Fe_2O_3)	4.03
Manganese (MnO)	Trace.
Lime (CaO)	.31
Magnesia (MgO)	.38
Potash (K_2O) (by difference)	.86
Loss on ignition	3.26
	100.00
Air-dried sand in air-dried clay	30.92

Brick earth at depth of 4 feet, Harrisburg.

[Dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	81.37
Alumina (Al_2O_3)	8.52
Iron (Fe_2O_3)	2.88
Manganese (MnO)	1.01
Lime (CaO)	.44
Magnesia (MgO)	.50
Potash (K_2O) Soda (Na_2O) (by difference)	2.40
Loss on ignition	2.88
	100.00
Air-dried sand in air-dried clay	28.08

Analysis of clay from an old clay pit at Harrisburg in sec. 25, T. 11 N., R. 3 E.

[Sample dried at 110°-115° C. R. N. Brackett, analyst.]

Silica (SiO_2) (free and combined)	75.93
Alumina (Al_2O_3)	11.05
Iron oxide (Fe_2O_3)	6.10
Lime (CaO)	.67
Magnesia (MgO)	.76
Potash (K_2O)	.72
Soda (Na_2O)	63
Phosphoric acid (P_2O_5)	.20
Loss on ignition	4.56
	100.62
Air-dried sand	37.62

The large amount of iron oxide and small amount of lime will give a deep red colored product.

The following analysis was made from the loess brick clay which came from the top of Crowleys Ridge, a short distance north of Spencer Creek, in Poinsett County:

Analysis of loess from Crowleys Ridge north of Spencer Creek.

[Dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	85.83
Alumina (Al_2O_3)	7.50
Ferric oxide (Fe_2O_3)	2.66
Manganese (MnO)	Trace.
Lime (CaO)	.32
Magnesia (MgO)	.35
Alkalies (by difference)	1.16
Loss on ignition	2.18
	100.00
Air-dried sand in air-dried soil	64.80

There is a striking similarity in the appearance of surface clay on top of Crowleys Ridge at Spencer Creek and the yellow clay that occupies the surface of the country between Crowleys Ridge and L'Anguille River, west of Harrisburg. The similarity is made more evident by comparing the analysis of the loess above given and the one following.

Analysis of upper layer of the "buckshot land" from Harrisburg, sec. 25, T. 11 N., R. 3 E.

[R. N. Brackett, analyst.]

Silica (SiO_2)	87.50
Alumina (Al_2O_3)	6.10
Iron oxide (Fe_2O_3)	2.69
Lime (CaO)	.63
Magnesia (MgO)	.36
Potash (K_2O)	.38
Soda (Na_2O)	.65
Phosphoric acid (P_2O_5)	.13
Loss on ignition	1.95
	100.49
Air-dried sand	77.48

CLAY INDUSTRY.

Common wet-mud bricks are made by W. P. Lancaster and J. B. Huey at Harrisburg. The product is made from the reworked Columbia or loess, which is 8 feet thick. The clay is tempered in soak pits, molded by horsepower machinery, dried on pallet and racks, and burned in up-draft scove kilns. The plant has a capacity of 8,000 bricks a day. Five to six days are required for drying, and ten to twelve days for burning. The green bricks can not be taken from the molds and placed in the sun immediately.

POPE COUNTY.

GENERAL GEOLOGY.

A part of Pope County and all of the other counties farther west along Arkansas River lie within the area of the Carboniferous coal-bearing rocks. The coal-bearing rocks in these counties do not differ greatly from those in Conway, Faulkner, White, and Pulaski counties farther east, where coal is not present, but the presence of the coal beds adds another factor that must be taken into account in dealing with the clays and clay industries.

The coal-bearing rocks in Pope County and the counties to the west are folded like those of the region to the east and southeast; in places these folds are sharp, in others they are gentle. The clay shales are interbedded with sandstones and with coal. As a rule they are compact where they lie under other beds, but where they have been exposed for a long time to the weather they become soft and plastic. In color they vary from almost black through various shades of gray, and weathering, become gray, yellow, or red. Among these clay shales that are associated with the coal seams the refractory clays are found.

In Pope County the sandstones usually cap hills or form ridges, just as they do in the counties farther east and south, while the shales as a rule underlie the valleys.

The sandstone ledge that forms the abrupt edge of Carrion Crow Mountain from Atkins to Galla Creek is widespread in western Arkansas, and was called by the Arkansas Geological Survey the Hartshorne sandstone, from Norristown Ridge, southwest of Russellville. This bed passes around the north side of Carrion Crow Mountain and forms the low hills from 2 to 4 miles north of Russellville. It also forms the rim of Tucker Mountain, from 4 to 8 miles north of Russellville, and crosses Illinois Creek to form the escarpments of Illinois Ridge, west of that stream. South of Tucker Mountain the rocks are bent into a trough or synclinal fold, and the Hartshorne sandstone bed is tipped up on edge to form Ouita Ridge.

The same bed of sandstone, after passing southward beneath the Ouita coal basin, comes to the surface again to form Norristown Mountain and Dardanelle Ridge and also Reeds Ridge, northeast of the ferry at Dardanelle. Special attention is called to this particular bed of sandstone because it furnishes the key to the structural geology of Pope County.

No workable coal is known in Pope County below the Hartshorne sandstone, though there is a bed 18 inches thick below it in Carrion Crow Mountain. The coal of the Ouita basin and that of the Shinn mines, south of Russellville, overlie it. If the Ouita bed existed about Carrion Crow Mountain it would be on top of the mountain, not on its flank. The Ouita coal bed lies south of Ouita Ridge because the sandstone dips southward, forming a basin or trough whose southern edge is Dardanelle Ridge. The Shinn mines lie north of Reeds Ridge because the sandstone of that ridge dips northward.

Important beds of shale and fire clay lie both above and below the Norristown sandstone. The shale above the Hartshorne sandstone has been called the Spadra shale, because it occurs typically at the Spadra coal mines. The Ouita coal bed at these mines and the same bed at the Shinn mines is in the Spadra shale, near its base. The Spadra shale is mostly a clay shale, though it is usually more sandy toward the top, and varies in thickness from 100 to 500 feet. The shales on the top of Carrion Crow Mountain belong to this set of beds. They everywhere accompany the Ouita coal bed and dip as the coal dips. Starting at Illinois Creek in sec. 29, T. 8 N., R. 20 W., these shales cover the whole area lying between Ouita Ridge and Dardanelle Ridge and west of Norristown Mountain. Below the Ouita coal bed—

that is, between the coal and the Hartshorne sandstone—lie 3 to 5 feet of fire clay and shale.

Below the Hartshorne sandstone there is a thick deposit of shale. The relations of this bed to the Hartshorne sandstone are well shown in the following section of Carrion Crow Mountain just north of Atkins:

Section of Carrion Crow Mountain.

	Ft.	in.
Hartshorne sandstone	45–180	
Shale	180–190	
Coal		18
Shale	160–200	

This shale can be traced throughout Pope County, in which it everywhere underlies the Hartshorne sandstone. It lies along the upper flank of Carrion Crow Mountain and of Tucker Mountain. Where Mill Creek cuts through Ouita Ridge it is well exposed below the Hartshorne sandstone to a thickness of about 300 feet.

This shale is underlain by a sandstone, and this in turn by still another shale. This last shale underlies the town of Russellville. The overlying sandstone does not seem to exist in the vicinity of Russellville, or if it does it is thin and unimportant. The great thickness of shales between the town of Russellville and Norristown Mountain therefore extends up to the lap of the Atoka formation. These shales probably have a thickness of 200 to 400 feet in the vicinity of Russellville. They form the lower flank of Carrion Crow Mountain, and the thin bed of coal there exposed is in these shales. They are well exposed on the Russellville-Dover road just south of Baker Creek and also along the west side of the same road along the base of Tucker Mountain. Buck Mountain, in T. 9 N., R. 19 W., is made of this shale, and in that mountain it has a measured thickness of 375 feet. Iron Ore Mountain, in T. 8 N., R. 18 W., is also made up principally of this shale.

CLAY DEPOSITS.

No analyses or tests have yet been made of the clay shales of Pope County. Where valuable shales are closely associated with workable coal beds, or even with coal beds which alone are not workable, it sometimes becomes economically possible to mine the coal and some of the shale together, with a view to utilizing the latter. There is no doubt that there are in Pope County enormous quantities of shales available for the manufacture of paving bricks, sewer pipe, and fire-clay goods. The occurrence of such raw materials in connection with abundant, excellent, and cheap coal and the cheap and convenient transportation afforded by Arkansas River afford highly favorable conditions for the building up of important manufacturing industries.

Material suitable for brickmaking covers a large area around Atkins, extending from W. H. Murphy's old brickyard at the base of Carrion Crow Mountain, in the SW. ¼ SE. ¼ sec. 20, T. 7 N., R. 18 W., eastward over several sections. This material varies much in depth, while at some places its continuity is broken by small gravel ridges.

On the line between the SW. ¼ NW. ¼ sec. 4 and the SE. ¼ NE. ¼ sec. 5, T. 7 N., R. 18 W., and over the greater portion of these lots, there is a fine light-colored clay about 4 feet thick. It is almost white in color, although there are spots of brown here and there toward the eastern side of the area.

Analysis of clay from sec. 5, T. 7 N., R. 18 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	90.49
Alumina (Al_2O_3)	5.22
Ferric oxide (Fe_2O_3)	1.38
Lime (CaO)	Trace.
Magnesia (MgO)	
Potash (K_2O)	
Soda (Na_2O)	
Loss on ignition	3.12
	100.21
Fine sand specimen	30.53
Water at 110°–115° C	1.60

In the NE. ¼ SE. ¼ sec. 26, T. 7 N., R. 19 W., there is an area of about 10 acres containing a soft brown and blue argillaceous shale, showing an exposure of 2 feet in the side of a creek. These shales are very soft and can readily be worked into a clay for the manufacture of fire-clay goods.

The clays around Russellville vary in color from a yellowish brown to an ashen white, according to the position of the material in the bed. In general the surface clay is darker than the underlying material. This difference in color varies in different places. In secs. 8 and 9, T. 7 N., R. 20 W., the upper clay is yellowish brown and varies in depth from 1 foot on the southern side of these sections to 3 feet along the bank of the creek that flows northeastward past Russellville. The lower division of this clay as exposed in the bank of the creek is pale yellow, almost white, and contains a great quantity of nodules of iron.

This buckshot clay rests immediately on the dark-blue argillaceous shales of the coal-bearing rocks and varies in thickness from 1 foot to 5 or 6 feet. On the slight ridge immediately south of Russellville, in the NW. ¼ sec. 9, it is not more than 1 foot thick, but in the land along the creek and between the Little Rock and Fort Smith Railway and the Dardanelle Railway it shows a thickness of 6 feet.

A short distance north of Russellville the thickness is reduced to 3 or 4 feet.

In area this clay covers secs. 4, 5, and 9 and the greater portion of sec. 8, T. 7 N., R. 20 W. It is also scattered through secs. 10, 11, 12, 13, and 14 of the same township and range. At Galla Creek station on the Little Rock and Fort Smith Railway, in sec. 19, T. 7 N., R. 19 W., it appears as a dark-yellow clay.

CLAY INDUSTRY.

Common bricks are made by the Mena Brick Company at its plant 2 miles southwest of Mena from a thin bed of clay overlying the shale. The clay is partly residual, since it contains many fragments of shale. The clay is first run through a Success crusher, then through a pug mill of the same make, and finally through a stiff-mud machine. About 4,000 bricks are made daily. The machine is run by a 40-horsepower engine. Usually 10 men are required to run the plant—two men in the pit, two feeders (one to temper the clay), one sander, two off-bearers, and two truckers. About one-half of the time is employed in molding and one-half in burning.

Another plant belonging to the same company is located 1½ miles from Mena, but it will probably be sold and removed to De Queen.

There is a brick plant at Russellville, known as the Russellville brick works, but nothing further is known concerning it.

There is a small brick plant at Atkins, with a capacity of 5,000 to 6,000 a day. The bricks are made by hand and burned in common scove kilns. It requires from two to five days for drying and ten to twelve days for burning. The bricks are made from the residual clay of the Paleozoic rocks. The size of the molds is 9 by 4 by 2½ inches; when burned the bricks measure 8½ by 3⅝ by 2¼ inches.

PRAIRIE COUNTY.

GENERAL GEOLOGY.

The southern half of Prairie County lying west of White River is level prairie land. The part that lies north of township 2, with the exception of a small area around Desarc, is chiefly wooded "slash land." The soil of the country east of White River is entirely alluvial, and the surface stands but a few feet above the low-water mark in White River.

Throughout the county White River has formed a bluff of varying height along its west bank. At Devall Bluff the level of the prairie land west of the river is 25 to 40 feet higher than the high-water mark in the river. The elevation of the depot at Devall Bluff is 186 feet, or about 7 feet lower than the depot at Helena.

The strata west of White River are of late Quaternary age. The surface material of the prairie land is a reddish clay loam or gray buckshot clay. On the higher ridges, where water does not stand for any great period, the surface clay and subsoil is a red clay very similar to the second-bottom or terrace clays along the west side of Crowleys Ridge in Lee and Phillips counties. In the low slash lands, which are covered with water for several months during the year, the surface clay was doubtless originally the same kind of material as that on the prairie lands. But the iron oxide of the prairie soils has been segregated into small limonitic concretions, which have received the local name of buckshot. The soils of the slash lands are therefore more or less leached and have a white to grayish color.

The character of the strata found in wells and in the bluff at Devall Bluff is shown in the following sections:

Section of bluff at Devall Bluff.

	Feet.
Yellow clay loam, in places buckshoty	10
Stratified reddish sand, very fine grained	8
Red plastic clay to bottom of gully	3

The yellow surface clay is used here for making brick. In the prairie land at Tollville, 6 miles southwest of Devall Bluff, the following well record was obtained:

Record of well at Tollville.

	Feet.
Yellow clay	3
Hardpan, gray clay	10
Reddish clay grading into a gray sand	20
Very fine quicksand, supplying water	10
Red clay	50
Soft gray clay	4
Gravel and sand; source of water	(?)

Over much of the prairie region there are numerous small spheroidal mounds which are rarely more than 2 feet high and 50 feet across the base. They are different from the larger mounds of undoubted human origin. The origin of these mounds has been a great mystery to all those who have studied them. By some they are thought to have been built by Indians, others have considered them to have been built by ants, and still others have attributed their origin to natural agencies, as winds and waves.

CLAY INDUSTRY.

Common building bricks are made at Devall Bluff. The Devall Bluff Brick and Tile Company manufactures a stiff-mud side-cut brick. The bricks are made from the red surface clay. They will check when dried too rapidly, and therefore have to be dried in covered sheds. The bricks are burned with wood in up-draft kilns. The capacity is 5,000 bricks a day. The output of bricks is largely governed by the local demand. They can not compete with bricks made at Little Rock, where convict labor is used in the yards.

PULASKI COUNTY.

GENERAL GEOLOGY.

The northwestern edge of the Tertiary beds crosses Pulaski County 2 or 3 miles northwest of the Iron Mountain Railway and keeps about parallel with it from Little Rock toward the southwest. Northwest of this Tertiary margin the rocks of the county are much folded, and are either Silurian or Carboniferous, while toward the south and east they are nearly horizontal and are Tertiary and Quaternary. The granites or syenites of the Fourche Mountain region are of earlier age than the Tertiary sediments to the south and east. They furnish the kaolins of Pulaski County, and have also probably been the source of much of the valuable clays of this and of adjoining counties.

CLAY DEPOSITS.

DISTRIBUTION.

But little is known of the details of the distribution of the clays in the extreme southern part of the county. South of the Fourche Mountain region the land is low and flat, and it is to be expected that ordinary brick clays are spread over that part of the county in great abundance. In the immediate vicinity of Fourche Mountain there is much pisolitic kaolin.

Pulaski County clays are best exhibited in the southwestern part of the city of Little Rock, and extend thence southwestward to the town of Alexander, on the Iron Mountain Railway and on the county line. Anywhere along this Tertiary margin a section drawn from the Paleozoic region on the northwest toward the southeast would show approximately the same geologic structure.

FOURCHE MOUNTAIN DISTRICT.

The feldspathic rocks of Pulaski County cover a total area of 8 or 9 square miles, all in the vicinity of Fourche Mountain, near Little Rock. White clays are found over this same area at various places. They also occur in the township next west, in the vicinity of Mabelvale, where no feldspathic rocks are known at the surface. The surface exposures are in secs. 5 and 9, T. 1 S., R. 12 W., and secs. 2, 10, 11, and 12, T. 1 S., R. 13 W.; and clays have also been found in wells in secs. 25, 26, 35, and 36, T. 1 N., R. 12 W.

In the NE. ¼ and the NE. ¼ NW. ¼ sec. 9, T. 1 S., R. 12 W., the exposures of clay occur on the middle Pine Bluff road about a quarter of a mile south of the end of the turnpike. It is exposed along both sides of the road for a distance of about 300 feet, and again in the road leading from the main road to D. Rausch's house for about 250 feet. At these exposures the clay where it is first seen has a dark pearl color and comes out in angular blocks that are somewhat stained with iron. Nothing is known of the depth or extent of this material, but it is probable that it will be found clearer of iron stain at no great distance below the surface, for the iron that coats many of the blocks has been washed into the crevices from the overlying surface sands. Small surface fragments seem to show that it extends to the middle of sec. 8, the section next west of that in which these exposures occur, and also into sec. 10 on the east. In the NW. ¼ NW. ¼ sec. 8 it is said to have been cut in a well at a depth of 14 feet. About 100 feet north of D. Rausch's house clay mingled with syenite bowlders is exposed at the surface. A light-gray clay is also reported from the W. ½ NW. ¼ sec. 15, T. 1 S., R. 12 W., but the locality has not been examined.

A well in the NW. ¼ NE. ¼ sec. 2 of this township is said to have penetrated white clay at a depth of 27 feet. A small exposure is also reported at the corner between secs. 3, 4, 9, and 10. Mr. E. C. Buchanan reports an outcrop in the SW. ¼ SE. ¼ sec. 3, T. 2 S., R. 13 W., similar to that found in sec. 9. Samples of this kaolin from the road near the middle of sec. 9 were analyzed and subjected to various practical tests in order to determine its availability as a china clay.

Analysis of Pulaski County kaolinite from sec. 9, T. 1 S., R. 12 W.

Silica (SiO_2)	46.27
Alumina (Al_2O_3)	38.57
Iron (ferric) oxide (Fe_2O_3)	1.36
Lime (CaO)	.34
Magnesia (MgO)	.25
Potash (K_2O)	.23
Soda (Na_2O)	.37
Water	13.61
	101.00
Water at 110°-115° C	1.57

It will be seen that the percentage of iron in this clay is rather high. Samples were tested by practical potters at Trenton, N. J., with the following results: The body of the crude clay burns a beautiful white, but a great number of rusty brown specks are scattered over this white ground, the largest of them one-sixteenth of an inch in diameter. This clay cracks in firing, but not enough to prevent its use for fine pottery if it were available in other respects. The iron in this clay seemed at first to offer a serious impediment to its availability, but some of the material was ground and thoroughly mixed and made into a paste and tested by firing. The samples came from the furnace in a much better condition than the crude clay—that is, it was free from the rusty brown specks—but the iron had only been evenly distributed through the mâss, and the result was that the sample came out with an ivory color instead of pure white. It takes the glaze well and is regarded by the potters as available for such wares as do not require a pure white body.

The clay at this locality (middle of sec. 9) as it comes from the ground is not plastic, nor is it soft enough to admit of its being taken out with a spade or shovel, but it is so hard as to require crushing. It comes out in angular blocks of various sizes; it is readily cut with a pick and has an earthy fracture. It is at first of a dark-pearl color, but upon drying takes on a cream color. The blocks from near the surface are covered with more or less iron stain, but this coating is readily removed, and it probably does not extend to any considerable depth.

Wells dug in secs. 25 and 26 and 35 and 36, T. 1 N., R. 12 W., disclose the existence of clay at various depths. At a small stream in the orchard near William Tarpley's house, in the NW. ¼ NW. ¼ sec. 36, a well 16 feet deep shows the following section:

Section in well in sec. 36, T. 1 N., R. 12 W.

	Ft.	In.
Gravel and sand	5	
Iron ore		2½
Joint clay	3	
Kaolinite	8	
Syenite (?) at bottom.		
	16	2½

In another well, 18 feet deep, on the top of the hill north of the well just mentioned, in the same orchard and nearer the house, no clay was found. The following is a section of this well:

Section in well near William Tarpley's house, in sec. 36, T. 1 N., R. 12 W.

	Feet.
Waterworn pebbles	6
Joint clay	8
Sandstone	4
Syenite at bottom.	
	18

These two wells are not more than 200 feet apart and the difference of elevation between their mouths is about 30 feet. It is evident that these clay beds are irregular in shape and thickness.

The clay found in Mr. Tarpley's well is very soft and almost milk white in color. Small patches of iron stain appear in places.

The following is an analysis of this clay:[a]

Analysis of clay from Tarpley's well.

Silica (SiO_2)	45.28
Alumina (Al_2O_3)	37.39
Iron (ferric) oxide (Fe_2O_3)	1.71
Lime (CaO)	1.83
Magnesia (MgO)	.29
Phosphoric acid (P_2O_5)	.06
Water, after having been dried at 110° C	13.49
	100.05

In the NE. ¼ SE. ¼ sec. 35, T. 1 N., R. 12 W., on the farm of J. M. Dickinson, a well 48 feet deep gives the following section:

Section of well in sec. 35, T. 1 N., R. 12 W.

	Feet.
Thin gravel at top.	
Red clay	16
White clay	1
Yellow pisolite (bauxite ?)	6
White clay	25
	48

Water was obtained before the last body of clay was passed through. Its actual thickness in this well is, therefore, not known.

In Mr. Dickinson's yard, about 100 feet east of this well, another well shows clay at 23 feet. In the latter well the yellow pisolite appears at 16 feet and the 1-foot band of white clay seen in the 48-foot well is absent. The following is a section of this well:

Section in well at house of J. M. Dickinson.

	Feet.
Thin gravel at top.	
Red clay	16
Yellow pisolite (bauxite ?)	6
Kaolinite in bottom	1
	23

The difference in elevation of the mouths of these two wells is not more than 4 feet. The specimens of clay obtained from the 48-foot well are of grayish-white color and show iron stains on the surface. There are signs of clay at the fork of the roads in the NE. ¼ sec. 26, but no systematic search has been made to ascertain whether it occurs in quantity or of a quality that will render it valuable.

In the neighborhood of Sweet Home station, in sec. 25, T. 1 N., R. 12 W., several wells are said to have passed into a white pipe clay, probably the white clay found in the village half a mile west of the station.

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[a] This analysis was made by Mr. W. R. Cravens under the direction of Dr. T. C. Van Nuys, professor of chemistry at the University of Indiana.

Those who may seek for clay in the Fourche Mountain district should bear in mind that it is not likely to be found on the hilltops, but rather in the lower grounds, where the rocks are kept constantly saturated with the acid waters by which decomposition is produced. It is surmised that places favorable to the formation of clay beds may be found in the northern part of sec. 3, T. 1 S., R. 12 W.

It should be added that at several places the lower portions of the bauxite beds of Pulaski County grade into clays.

MABELVALE DISTRICT.

The Mabelvale district lies about halfway between the Fourche Mountain district, south of Little Rock, and the Saline County district. No feldspathic rocks have been observed in the immediate neighborhood of Mabelvale, but a band connecting the Fourche Mountain and the Saline County areas would embrace Mabelvale. This fact and the existence of bauxite seem to suggest the probability that syenites exist not far beneath the surface in the vicinity of Mabelvale. The clays in this district are all more or less pisolitic, and are believed to be simply the kaolin varieties of bauxite. Their chemical composition, however, seems to suggest the possibility that some of them may be available as china clays.

On the middle of the east side of the NW. ¼ sec. 10, T. 1 S., R. 13 W., about 150 yards south of the west end of the railway siding at Mabelvale station, on the St. Louis, Iron Mountain and Southern Railway, there is a deposit of bauxite which merges into pisolitic clay, the two covering about 25 acres. The material outcrops at many points, but it is concealed for the most part by a thin covering of sand and pebbles and nodules of sandy limonite. The covering becomes gradually more abundant toward the higher ground and thins out on the margins of the knolls. But little is known of the actual area covered by the clay. A well said to have been dug 92 feet deep at the house of J. W. Hopkins, within 300 feet of the western outcrop, is reported to have penetrated 8 feet of soil and then "soapstone," or gray clay, all the rest of the way.

The following analysis shows the character of the clay from the Mabelvale locality:

Analysis of pisolitic clay from SE. ¼ NW. ¼ sec. 10, T. 1 S., R. 13 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	45.20
Alumina (Al_2O_3)	37.60
Iron (ferric) oxide (Fe_2O_3)	3.00
Lime (CaO)	.89
Magnesia (MgO)	Trace.

Potash (K_2O)	0.06
Soda (Na_2O)	.69
Water (loss on ignition)	13.54
	100.98
Very fine sand	.25
Water at 110°-115° C	.62

This contains a large amount of iron, but it is probable that material found at greater depth will contain less iron than that nearer the surface.

White pisolitic clay is also exposed in the NE. ¼ NE. ¼ sec. 10, less than half a mile southeast of the railway station. This material crops out in the road. Just south of the road, about 15 paces from it, a well was at one time put down, and the following is reported as the section passed through:

Section in well in sec. 10, T. 1 S., R. 13 W.

	Feet.
Yellow clay soil (dug)	3
Pisolitic clay (dug)	14
Pisolitic clay (bored)	14
	31

The clay was not penetrated at this depth, so that its total thickness is not known. This well record is also said to bear out the suggestion that the clay becomes softer and cleaner as the depth increases. The extent of this deposit is not known, but it probably does not exceed 5 acres.

The analysis given below shows that this material contains less iron than the sample taken near Mr. Hopkins's place, in the same section.

Analysis of pisolitic clay, NE. ¼ NE. ¼ sec. 10, T. 1 S., R. 13 W.

Silica (SiO_2)	48.05
Alumina (Al_2O_3)	38.92
Iron (ferric) oxide (Fe_2O_3)	1.19
Lime (CaO)	.58
Magnesia (MgO)	.45
Potash (K_2O)	.18
Soda (Na_2O)	.28
Water (loss on ignition)	10.86
	100.51
Water lost at 110°-115° C	.46

Another deposit, which shows in the form of bauxite at the surface, but which will probably be found to contain a pisolitic clay a short distance below the surface, occurs in the SW. ¼ SE. ¼ sec. 2, T. 1 S., R. 13 W., and nearly or quite on the line between secs. 2 and 11, the greater part of it lying between the forks of the road at this point. The total area covered by this deposit probably does not exceed 4 acres. Where this material is exposed at the surface it is pisolitic, hard, and iron stained. A well sunk in it showed that it resembles the other deposits of this region in being softer and whiter below the surface. The surface fragments have been used somewhat for building chimneys and for setting boilers, to which purposes its fireproof qualities make it well adapted.

In the SE. ¼ SW. ¼ sec. 12, T. 1 S., R. 13 W., loose fragments of pisolitic clay are scattered over the surface and a few small exposures are visible. There are no means, however, of knowing the nature or extent of this deposit, but if this kind of clay proves to be valuable it would be worth while to prospect at this place.

The following is the record of a well dug at Mabelvale, in the NE. ¼ NE. ¼ sec. 10, T. 1 S., R. 13 W., in the yard of Mr. A. W. Norris:

Section in well at Mabelvale.

	Feet.
Yellow surface clay	5
Reddish clay	1
Dove-colored joint clay or "soapstone" clay with occasional "iron pots" and some manganese streaks	16
Ferruginous sandstone	2
Black clay in the bottom.	
	24

The dove-colored clay of this section is soft and unctuous, and is popularly known as "soapstone." The "iron pots" (hollow masses of iron ore, some a foot in diameter, resembling waterworn cobbles) found in this bed are so large and so sparsely scattered through the bed that they can not seriously interfere with the use of the clay.

This clay bed is probably widespread in the neighborhood of Mabelvale, lying at or near the surface. It was passed through in digging the well in the public square at Mabelvale. The section of this well given below is a sort of average made up from several reports, which disagree somewhat in minor details, but not in any essential features.

Section of well in public square at Mabelvale.

	Ft.	In.
Yellow surface clay	5	
"Soapstone clay"	10–15	
Ferruginous sandstone	2	
Black clay	10	
Limestone		8
Black clay	10	

The following analyses give the composition of the "soapstone" clay bed. No. 1 is an average sample from the well at Mr. Norris's house. The analysis was made by the Geological Survey of Arkansas. No. 2 was sent for analysis by McCarthy & Joyce, of Little Rock, to

Prof. W. B. Potter, of St. Louis. A copy of the analysis was kindly furnished by Mr. Norris.

Analyses of "soapstone" clay, from well of A. W. Norris, NW. ¼ NE. ¼ sec. 10, T. 1 S., R. 13 W.

	1.	2.
Silica (SiO_2)	65.27	60.79
Alumina (Al_2O_3)	18.75	19.73
Oxide of iron (Fe_2O_3)	7.34	5.94
Lime (CaO)	.81	.37
Magnesia (MgO)	1.26	.72
Potash (K_2O)	1.10	1.93
Soda (Na_2O)	.81	
Loss on ignition (H_2O)	6.88	10.77
	100,22	100.25
Water lost at 110°-115° C	9.46	....
No sand.		

This clay is convenient to transportation and well adapted to the manufacture of paving bricks, sewer pipes, and probably fire bricks. The beds are horizontal, and at points where the surface is somewhat lower than at Mr. Norris's can be reached without much stripping.

The following sections of wells in the vicinity of Mabelvale, although evidently imperfect and unsatisfactory, are given for what they are worth. All references here are to T. 1 S., R. 13 W.

V. L. Cochrane, in the SW. ¼ NW. ¼ sec. 11, reports "17 feet of fire clay and red clay." The so-called fire clay is possibly the same as the buff clay in Mr. Norris's well.

Mr. Rowland, on the NW. ¼ SW. ¼ sec. 11, reports "22 feet of fire clay and red clay." This section without doubt exposes the same beds as does that given by Mr. Cochrane near the blacksmith shop.

Mr. Rowland also reports, from the SW. ¼ NW. ¼ sec. 11, "13 feet of fire clay and yellow clay, with from 2 to 4 inches of ferruginous sandstone interbedded."

Mr. S. E. Emerson, in the NE. ¼ NE. ¼ sec. 11, reports the following well section:

Section of well in NE. ¼ NE. ¼ sec. 11, T. 1 S., R. 13 W.

	Feet.
Red clay	3½
Gray "fire clay and black clay"	20
Gray clay	18

These gray clays and so-called fire clays are probably the same as the buff clays passed through in Mr. Norris's well. If this supposition is correct, these sections show that the buff clay is a widespread bed, underlying all the higher grounds east and southeast of Mabelvale, and probably a much wider area still, while it is cut out in the low grounds along the streams. Should there be a demand for these clays they will be found most accessible in sec. 3 and on the lower grounds about the bases of the ridges, where they are not obscured by a covering of gravel and sand and soil.

LITTLE ROCK DISTRICT.

BRICK CLAYS

The folded Paleozoic rocks pass beneath the city of Little Rock, and on these folded beds rest the Tertiary clays and sands of the southwestern part of the city. It should be observed also that these Tertiary beds are nearly horizontal, that they thin out toward the north, and that similar beds underlie the region south of Fourche Mountains.

At several places in the city of Little Rock the folded Paleozoic rocks may be seen standing almost on end. The famous "little rock" itself, on which rests the south end of the railway bridge at the foot of Main street, is a folded and wrinkled Paleozoic bed.

Only a few paces south of the river bank these older beds are not exposed, but the surface is made up of loose materials. One of the best sections seen near the center of the city was exposed when the excavations were made for the foundations of the Masonic Temple, on the corner of Fifth and Main streets, in June, 1890. The section exposed was as follows:

Section in excavation for Masonic Temple at Little Rock.

	Feet.
1. Mottled red clays with chert pebbles, becoming more sandy at the base	7–9
2. Reddish-brown clayey sand with brown chert pebbles	2–3
3. Red, gray, and white mottled plastic, sandy clay with a few large and angular sandstone fragments at the top of the bed (exposed)	3

The upper surface of No. 3 is irregular, as if it had been eroded before the overlying beds were laid down upon it. These are probably the overwashed portions of the Tertiary series, the equivalents of which on the Atlantic seaboard are called the Appomattox formation. These rehandled beds of mottled clays, sands, and gravels are found at the surface in nearly every part of the city. They are well exposed in the cuts, even on the top of Capitol Hill, in the vicinity of the school for the blind, and at many other places. Below these gravelly beds lie the undisturbed Tertiary strata, which in and about Little Rock consist chiefly of limestones, shales, or clays, and sands.

Mr. C. E. Siebenthal, while in the employ of the Arkansas Survey, collected many data regarding the geology of southwestern Little Rock. He is of the opinion that there are four pretty constant and well-defined beds in the series of sediments resting upon the Paleozoic rocks. These are, beginning at the base, (1) yellow calcareous clay or marl; (2) dull gray fossiliferous limestone; (3) soft, dark unfossiliferous shale; (4) olive-green clay, probably derived by weathering from No. 3. Above this type section are found various combinations of sands and gravels and soil.

Of these beds the ones of interest in connection with the subject of clays are the shale bed (No. 3) and the olive-green clay. The green clay is well exposed on the Seventh street pike, between West Spring street and West Sherman street, where it rests upon upturned Paleozoic rocks, which are exposed at this place. The following exposures and well records show the depth of the shales and clays at various points in the city:

Section in D. T. Coffman's well, at northwest corner Eighteenth and West Sherman streets, Little Rock.

	Feet.
1. Soil, gravels, and white clay	16
2. Soft shale, yellow above, blue below	14

West of the railway the olive-green clay is exposed in the road cut near the Catholic cemetery, in the gullies south of the cemetery, in the gully west of the hospital, and in another gully about 500 feet southwest of the hospital. It is also exposed in the bed of the branch just east of the hospital, and also toward the top of the ridge to the east.

The following is the record of a well put down west of the railway, about 300 feet northeast of the center of the south side of sec. 8, T. 1 N., R. 12 W., as reported by Mr. Siebenthal.

Section of well in sec. 8, T. 1 N., R. 12 W.

	Ft.	in.
Gravel and sand	6	
"Mulatto" clay	8	
Gray clay		10
Yellow clay	10	
Gravels and sandy clay	8	

East of the railway near the center of sec. 16, T. 1 N., R. 12 W., there are several exposures of the shale and of the olive-green clay. On the east slope of the ridge that runs along the east side of sec. 16 this same green clay is exposed here and there. It is exposed also in the gullies beside the road leading southwest from the Arch street pike, in the SW. ¼ sec. 15.

A well on the east side of the Arch street pike, 200 feet south of the northern edge of sec. 15, passed through soil, gravel, yellow clay, and tough blue clay, and got water at 27 feet in gravel. This clay bed is probably the same as that exposed in the gully on the slope of the hill below, where the road turns southwest from the Arch street pike.

A well at the southeast corner of Arch and Twenty-third streets passed through 8 feet of gravel and sandy clay and 10 feet of yellow and blue Tertiary clay. This is doubtless the same blue clay bed again.

At the end of the ridge east of the Rapley house and north of Pettifer's brickyard the olive-green clays are well exposed to a thickness of 40 to 45 feet. The olive-green clay and dark shale were found in wells and cisterns dug about Cumberland, Rock, Twentieth, and Twenty-first streets.

The following records were gathered by Mr. Siebenthal:

A well at Fifteenth and May streets passed through the Tertiary shale.

A well near the northwest corner of Thirteenth and Jones streets passed through 10 feet of soil and gravel and 18 feet of shale.

A well 14 feet deep at Fourteenth and Marshall streets passed through dark shale most of the way.

A well at the southeast corner of Twenty-seventh and Wolfe streets passed through 10 feet of gravel and sandy clay and 20 feet of dark Tertiary shale.

A well on Mr. Robert's place, Twenty-second street, between Commerce and Sherman, passed through 19 feet of soft Tertiary shale, and two other wells in adjoining lots to the east penetrated 60 feet of the same soft shale.

A well at the corner of Sixth and College streets passed through 30 to 35 feet of dark Tertiary shale.

A well bored by the Cotton Belt Railway Company on Rector avenue between Third and Fourth streets passed through the following:

Section in well of Cotton Belt Railway Company, Rector avenue, Little Rock.

	Feet.
Soil	12
Dark Tertiary shale	20
Paleozoic shale	29
Sand (?)	6

A well on Ninth street opposite the arsenal is reported by the digger to have the following section:

Section on Ninth street near the arsenal, Little Rock.

	Feet.
Soil and clay	20
Tertiary shale	8
White gravel	4

These facts and others not here given lead to the belief that the Tertiary clays follow the brow of the hill where the Arch street pike descends the slope about the middle of sec. 15, encircle the narrow valley that heads about the corner of Nineteenth and High streets, pass around it, and thence extend southward along the slope of the hill that runs along the east side of sec. 16, return northwestward along the valley through which the Iron Mountain Railway passes, appear again in the vicinity of the hospital on the west side of the railway, and thence around the hills west of the hospital. Of course, it is understood that these beds are nearly horizontal and that they pass right through the hills mentioned and have their edges exposed only on the slopes of the ridges. Almost everywhere, however, the outcrops are concealed by the soil and surface materials that have fallen down over them.

The elevation of the outcrop varies somewhat, but it lies for the most part between 260 feet and 302 feet above sea level.

In and near the city of Little Rock there are only a few places at which the clays can now be worked advantageously. This condition is due to the value of the land for building purposes, and not to any defect of the clays themselves. In spite of this it is possible that there may be places in the southwestern part of the city where the clays could be worked, while the nearness to market and to transportation would be in favor of such an enterprise.

On the south side of the river there is a brownish-yellow brick earth similar to that which forms the surface in sec. 28, T. 2 N., R. 12 W., overlying the other clays in different places west and south of Little Rock.

Between the high shaly hills on which the asylum for the insane and the reservoir of the city waterworks have been erected and the river there is a narrow strip of this same brownish-yellow clay. It lies in a long, narrow belt between the hills and the bottom land of the river. At Ward's old brickyard this brick loam rested directly upon a red sand. The section is as follows:

Section at Ward's old brickyard, Little Rock.

	Feet.
Brick earth removed at other places in the same belt	2
Stiff, hard red sand	4
Light iron-gray or yellowish sand	5

Between the point where the St. Louis, Iron Mountain and Southern Railway crosses Sixteenth street and the outcrop of the blue shales and quartz ledge at Nineteenth street a small deposit of this brownish-yellow brick earth appears to have been laid down in a sort of pocket among the shales, with its opening toward the south. The yellowish loam here has a depth of about 3 feet.

Another small deposit of the same material is found on the corner of Rector avenue and Eighteenth street. Here the brownish-yellow loam has a thickness of 2 to 3 feet. It is underlain by a bluish pebbly clay, mixed with sand. A well bored through this clay shows it to have a thickness of 19 feet. It is underlain by sandy clay. The underlying sandy clay is seen in the bottom of a small stream that runs along the south side of the old Bragg brickyard. The clay covers only a small area, most of it lying between gravel ridges.

On Arch street between Twenty-fourth and Twenty-sixth streets, at C. W. Clark's old brickyard, the brick clay was about 2 feet thick before it was exhausted, and was underlain by a stiff, bluish-red, streaked clay containing pebbles, which is said to be underlain by gravel.

The greater portion of a well close to Clark's yard, 23 feet deep, passed through gravel, below which lay black mud. Another well, 16 feet deep, does not reach the black mud, but ends in the gravel.

JOINT CLAYS.

The next clay below the brownish-yellow brick clay is a stiff, hard clay having a tendency to break into small cuboidal fragments when exposed to the air. Its tendency to break is the chief objection to its use for manufacturing purposes. Ware containing any of this "joint" clay, as it is called, is likely to break in drying.

This joint clay varies somewhat in different places as regards color, having a blue or red tint according to its position, but the color has no apparent effect on its texture or its tendency to break when exposed to the drying action of the atmosphere. It appears to be very persistent, being found in nearly every opening in the district that passes through the upper beds. It is not confined to the brownish-yellow brick-earth area, but underlies the chocolate clay and some of the gravels.

In the district north of the river this joint clay is red and is seen in the stream running through the small bayou on the north side of Big Rock, where it underlies 2 feet of chocolate clay. In the wagon road near the Fort Smith crossing of the St. Louis, Iron Mountain and Southern Railway it varies from 3 to 5 feet in thickness and overlies a red sandy clay. In Mr. Vestal's portions of secs. 26 and 27, T. 2 N., R. 12 W., it lies near the surface. In the NE. ¼ NE. ¼ sec. 17, T. 2 N., R. 11 W., the clay underlying the brownish-yellow loam is very compact.

In the NE. ¼ NW. ¼ sec. 21, T. 2 N., R. 11 W., the clay underlying the brownish-yellow loam is a whitish-yellow and blue mixed sandy clay 20 feet thick and rests upon 12 feet of mottled clay.

On the south side of the river a blue clay underlies the other clays at most places where deep cuttings have been made. This clay, which lies just below the brownish-yellow surface clay, is a light-blue iron-stained clay containing quantities of pebbles and sand and nodules of limonite.

The underlying clay on the corner of Rector avenue and Eighteenth street is bluish gray and contains pebbles. At this place it is 19 feet thick. It is also seen in the bank of a small stream a short distance south of this place.

At C. Clark's old brickyard the brick earth is also underlain by this light-blue sandy clay. This same blue clay extends southward over the ground formerly used as a brickyard on the south side of Twenty-fifth street.

In the banks of the small stream that runs through the cemetery and westward across the Sweet Home turnpike, close to the Confederate soldiers' cemetery, there is a heavy deposit of a stiff, red joint clay.

On the Arch street turnpike a little west of the place where the new road joins the turnpike a bed of blue and red mottled joint clay is exposed in a gully washed out by the rain.

For practical purposes these joint clays are not in much demand. Their tendency to "joint" or break up into small blocks whenever exposed to the weather makes their use difficult for any purpose except with great care, and even then no reliance could be placed upon them if worked alone.

If judiciously mixed with other clays they might be used for some classes of ware. A mixture of the stiff red clay and the brownish-yellow surface clay has been successfully used for making flower pots. A few lengths of drain tile, turned upon the potter's wheel, dried and burned very satisfactorily.

CHOCOLATE CLAYS.

The chocolate clays are found only in remnants or patches in various parts of the district.

At the union depot in Little Rock the chocolate clay forms the surface of the flat bottom of the cove in which the depot is situated. It has here a thickness of 2 to 3 feet.

In the small valley formed by the stream crossing the Sweet Home turnpike and skirting the southern side of the gravel ridge in the SE. ¼ sec. 11, T. 1 N., R 12 W., the chocolate clay is found on both sides of the stream and has a thickness of from 1 to 2 feet. On the hill at the tollgate between this stream and Fourche Bayou, about one-half mile from the place just mentioned, the same bed of chocolate clay appears.

The following section shows the relation of the clays at this hill:

Section at hill at tollgate.

	Feet.
Chocolate clay	3
Red clay	6
Blue clay.	

In Big Rock Bayou, in sec. 21, T. 2 N., R. 12 W., chocolate clay 2 feet thick overlying a blue clay occupies the greater part of the bottom lands around the bayou.

A partial analysis of the clay northwest of the union depot at Little Rock shows the following constituents:

Analysis of chocolate-colored clay northwest of union depot, Little Rock.

[J. P. Smith, analyst.]

Silica (SiO_2)	70.05
Alumina (Al_2O_3)	14.56
Ferric oxide (Fe_2O_3)	6.20
Lime (CaO)	.74
Magnesia (MgO)	1.12

Potash (K_2O)	Not determined.
Soda (Na_2O)	
Loss on ignition	4.45
	97.12
Sand, very fine, but some coarse particles	11.83
Water at 110°-115° C	4.48

When the chocolate clay is washed, it makes a smooth paste of uniform color. This may probably form a good base for the manufacture of some classes of terra-cotta ware, but great care must be taken to see that it is dried at a uniform rate over all the work, as otherwise the clay has a tendency to break into small blocks.

A portion of the chocolate clay found in the valley at the union station was washed, and the slip so formed was allowed to stand for some time. The surplus water was filtered off and the whole was allowed to stand for two weeks. On drying it formed a smooth-surfaced even-textured clay and retained its characteristic chocolate color.

BOTTOM CLAYS.

The bottom lands that lie along Fourche Bayou and form Fourche Island are overlain in many places by a dark-bluish clay. On drying this clay becomes ashy gray and exhibits patches of iron or rust stains. When wet the clay is tough and plastic, and in drying it becomes hard and shows a tendency to crack where exposed to the heat of the sun.

An exposure of this clay is seen in the stream along the track of the St. Louis, Iron Mountain and Southern Railway, near the point where that road crosses Fourche Bayou, in the NE. ¼ SE. ¼ sec. 17, T. 1 N., R. 12 W. In this stream the clay bed is about 4 feet thick and extends along the railroad for nearly a quarter of a mile. It is also shown at various other places in the cuttings throughout the bottom lands.

This clay is comparatively free from sand and when wet is very tough. When worked properly it may be used for making a good grade of pressed front or ornamental bricks and may possibly be utilized for the manufacture of ordinary drain tile. In appearance and texture, as well as in position and apparent origin, this clay greatly resembles the clays of the bottom lands of Terre Noir and Bradshaw creeks, which were formerly used in the manufacture of bricks and drain tiles by Maj. Jesse A. Ross at his brick and tile factory near Arkadelphia.

In working this clay considerable attention will have to be paid to its proper mixing and tempering, and also to the drying of the bricks or tiles after they have come from the machine.

This clay will work better and easier if dug in the fall and worked over during the winter preparatory to its final tempering and manufacture in the following summer. The low-lying position of the pits will require the clay that is to be thus worked to be removed to a higher situation, where it will be beyond the reach of the overflow of the bayou during the late winter and early spring rains. It will be an advantage to house the clay in covered pits, where it can be protected from excessive wet and where at the same time it will not become too dry for working. If it contains a considerable quantity of its natural moisture, less work will be required in mixing and grinding and a much better final article will be produced.

Like the other clays found in the bottom lands of the State, this clay holds a considerable percentage of water, and at the same time it parts with the water very slowly. For this reason it will be necessary to work this clay in as dry a condition as possible. The slow parting with its combined water renders the drying of the bricks and tiles made of this or similar clays a rather long process and one which must be very carefully attended to. Such clays can be best dried under cover, in sheds so constructed that, as far as possible, a uniform amount of air and heat will be allowed to come in contact with the newly made bricks or tiles and strike them as equally as possible. At some seasons of the year, and for reasons given above, an artificial drier may probably be the most advantageous. Probably the drier may be economically used at all times, as clays of this class can not be dried in the air sufficiently to be ready for the kiln within fifteen to twenty days. Great care must be taken that the bricks or tiles are sufficiently dry before they are placed in the kiln. If not thoroughly dry when put into the kiln, the bricks will crack and the tiles have a tendency to split longitudinally.

M'ALMONT DISTRICT.

West of the village of McAlmont, in the center of sec. 16, T. 2 N., R. 11 W., on the line of the St. Louis, Iron Mountain and Southern Railway, and in the NE. ¼ NE. ¼ sec. 29, T. 2 N., R. 11 W., the railway crosses a bank of clay running in a northwest-southeast direction. The northern boundary of this field begins near Tremble Lake, in the SW. ¼ SW. ¼ sec. 9, T. 2 N., R. 11 W., and passes northeastward, curving gently round it until it crosses the St. Louis, Iron Mountain and Southern Railway 1 mile north of McAlmont. It there crosses the Memphis wagon road and, turning somewhat abruptly, comes west, crossing the wagon road to Galloway, a short distance east of McAlmont. The bank then curves round toward Ink Bayou. It follows the edge of the bayou for some distance and again crosses the public road and railway in the SE. ¼ sec. 20, T. 2 N., R. 11 W. This area is overlain to a great extent by a brighter colored loam than that found in the old brick field around Argenta, and from appearances it seems capable of making a finer brick.

This bank is not altogether composed of yellowish loam. North of McAlmont the loam gives place to a stiff clay, which changes in color from bright red to drab and dark red as it approaches the outer point of the area comprised within the above limits. This clay, although differently colored, is apparently of the same nature. It is plastic, greasy to the touch, and works smoothly. Each color works into the other, forming a perfectly homogeneous mass. A well bored through the red clay in the SE. ¼ SE. ¼ sec. 9, T. 2 N., R. 11 W., shows it to have a thickness of 12 feet and that it rests upon fine sand.

In a ditch along the side of the railway and between it and the Memphis wagon road three beds are exposed. These clays are red, drab or gray, and bright red. The red clays at the bottom do not appear to have the same texture as the others. Where exposed to the air these clays become dried and show a tendency to break up into small pieces, somewhat in the same style as the joint clay, but when wet they are stiff and tenacious.

This clay bank follows the same general course as that just mentioned. It begins at Clear Lake, and from that point a mulatto sand succeeds it to the Galloway road at McAlmont. West of McAlmont the face of the bank becomes somewhat paler in its upper division. The light-colored material forms no great proportion of the bank, and in the many cuttings made by the small streams and rain the red clay is seen everywhere underlying it. Where the bank is crossed by the public road west of Buchanan's the light-colored and mulatto soils appear to be wanting in the face and are confined to the middle level of the country, and form a terrace, the edge of which is seen on the road a short distance west of Buchanan's, where it overlies a red silty sand and has a depth of 3½ feet. It, however, gradually disappears toward the west, and at the old graveyard on the Little Rock and McAlmont wagon road, about 2 miles east of the lower railroad bridge over Arkansas River, it is replaced by this red sand. The underlying clays in this field are not easily determined.

CLAY INDUSTRY.

The various kinds of clays found in Pulaski County have already been discussed. They include the kaolins of Fourche Mountain, pottery clays, clay shales suitable for the manufacture of paving bricks and fire bricks, and the more common surface clays suitable for the manufacture of common building bricks. Common brick clay is the only clay in the county now used, and Little Rock the only place where it is manufactured into bricks.

There are at present three brick plants in Little Rock engaged in the manufacture of brick. One of the largest plants is the Arkansas Brick and Manufacturing Company, established in 1897. The plant is well equipped with modern machinery for molding, drying, and burning. Stiff-mud and dry-pressed bricks are made. The stiff-mud bricks are molded in a Chambers machine and the dry-pressed bricks in a Ross-Keller dry press. The bricks are dried in a Standard drier and burned in Swift's patent up-draft grate kilns. It requires forty-eight hours to dry and eight to ten days to burn the bricks. Ten kilns, 72 feet by 24 feet inside measurement, are in use. The output of the plant is 150,000 stiff-mud and 25,000 dry-press bricks a day.

ST. FRANCIS COUNTY.

GENERAL GEOLOGY.

St. Francis County is divided into three natural subdivisions—(1) the eastern, or St. Francis River bottom; (2) the central, or Crowleys Ridge; and (3) the western, or the prairies.

The St. Francis River bottom is a flat area which is but 212 feet above sea level at Madison, on St. Francis River. East of this the country rises somewhat. The elevation of Forrest City, on the west side of Crowleys Ridge, is 251 feet. East of the ridge the surface material consists entirely of alluvial sand and silt.

The Chicago and Rock Island Railroad, which runs from Memphis to Little Rock, crosses Crowleys Ridge at Forrest City. The following interesting section is shown along the railroad from Madison, on St. Francis River, to Forrest City:

Section of Crowleys Ridge at Forrest City.

	Feet.
Loess (unstratified)	10
Dark loam, a phase of the loess	3
Yellow clay loam, a phase of the loess	10
Loess unstratified, containing irregular lime concretions	6
Stratified loess, bedding brought out in narrow bands by yellow iron-oxide coloring, containing many small land shells, also many round lime concretions of all sizes up to that of a base ball, the whole bed becoming more and more sandy toward the base	16
Hidden	2-3
Gravelly sand, streaked yellow with iron stain and cross-bedded	3-4

Still farther east, at a lower elevation than the base of the above section, the following section was obtained:

Section 1¼ miles east of Forrest City.

	Feet.
Loess (unstratified)	10
Dark loam, a phase of the loess	3
A reddish-yellow phase of the loess	6
Loess, indistinctly stratified	15
Yellow clay loam	3
Fine drab argillaceous sand	3
Coarse gravel (Lafayette)	5
Gray sand, cross-bedded in places and elsewhere interstratified with thin layers of light-drab clay	2
Dark to black sand, very fine, containing lignite, the dark color being due to carbonaceous matter	2-3

On the east side of Crowleys Ridge, near the mouth of Big Crow Creek, and also in the bed of the creek about one-half mile from its mouth, there is a series of calcareous marine deposits containing numerous Tertiary fossils, which belong either to the Jackson or Claiborne horizons. The collections which have been made contain about an equal number of Jackson fossils and of fossils of Claiborne age. While the exact horizon may be somewhat doubtful, the fossils prove conclusively that the strata belong to the lower Tertiary beds.

The fossils found in the strata along Big Crow Creek, east of Forrest City, have made it possible to determine the age of the older strata along Crowleys Ridge. The ridge is, therefore, a remnant of the old Tertiary plain which once extended unbroken from the foot of the Paleozoic hills in eastern Arkansas eastward to the present bluffs east of Mississippi River.

CLAY DEPOSITS.

The clays of St. Francis County are the common brick clays found along the top and sides of Crowleys Ridge and the yellow clay loam of the prairie country west of the ridge.

Crowleys Ridge throughout the county is capped with loess, which is found in different phases. In the railroad cut east of Forrest City there are no less than four different varieties of the loess. In places it is a buff to gray nonstratified mass, containing a large percentage of lime concretions and land shells. Both above and below lie beds of stratified loess, which in places is a reddish-yellow clay loam, containing little or no lime carbonate and free from shells. The yellow clay loams of the loess are much better adapted to brick manufacture. The bricks burn to a solid red and are much stronger and stand more heat than bricks made from the calcareous loess.

The country west of the ridge has a surface covering of yellow clay similar to the yellow clay of the loess, but of much later age. In places its thickness ranges from about 15 feet at the western edge of St. Francis County to 40 feet or more near the foot of Crowleys Ridge.

The persistency of the surface clay is shown in the following well sections:

Section of well at Palestine.

	Feet.
Red clay	12–14
Quicksand	12–14
White clay	6– 8
Heavy gravel	12

Section of well at Brinkley, about 3 miles west of St. Francis County.

	Feet.
Yellow clay	12
Yellow sand	17
Blue mud	1
Quicksand	6
Hard clay	25
Coarse gravel	(?)

The yellow surface clay which occurs so extensively over the prairie region west of the ridge forms in places the limonite buckshot land.

Below are given three analyses of the brick clays from St. Francis County:

Analysis of loess soil from Crowleys Ridge, at Forrest City.

[J. P. Smith, analyst.]

Silica and insolubles	76.30
Ferric oxide (Fe_2O_3) Alumina (Al_2O_3)	16.86
Lime (CaO)	1.00
Magnesia (MgO)	1.22
Potash (K_2O)	.54
Soda (Na_2O)	.89
Phosphoric acid (P_2O_5)	Trace.
Loss on ignition	2.83
	99.64

Analysis of buckshot clay from Goodwin Prairie, 4 miles northwest of Goodwin station.

[J. P. Smith, analyst.]

Silica (SiO_2)	82.52
Alumina (Al_2O_3)	7.50
Iron oxide (Fe_2O_3)	4.32
Lime (CaO)	Trace.
Magnesia (MgO)	.40
Potash (K_2O)	.52
Soda (Na_2O)	.63
Manganese (MnO)	Trace.
Phosphoric acid (P_2O_5)	Trace.
Loss on ignition	3.64
	100.34
Water at 115° C	7.82

The following sample was taken from the material about a newly dug well about 4 miles northeast of Goodwin station, on the railway:

Analysis of hardpan from Goodwin Prairie.

[J. P. Smith, analyst.]

Silica (SiO_2)	84.04
Ferric oxide (Fe_2O_3)	3.70
Alumina (Al_2O_3)	6.32
Lime (CaO)	.34

Magnesia (MgO)	Trace.
Potash (K_2O)	0.91
Soda (Na_2O)	.80
Manganese (MnO)	Trace.
Phosphoric acid (P_2O_5)	.00
Loss on ignition	3.32
	99.43
Water at 115° C	1.40

CLAY INDUSTRY.

The only clay product manufactured in the county is common building brick, made from the loess by the Choctaw Brick and Tile Company, of Forrest City. The clay is hauled from the pit to the machine by a team and scraper, mixed in a steam pug mill, and molded in a Chambers end-cut, stiff-mud machine. The bricks are dried by steam, which requires one to two days. They are burned in up-draft kilns, having a capacity of 200,000 bricks. Wood is used as fuel. The plant has a capacity of 20,000 bricks a day.

SALINE COUNTY.

GENERAL GEOLOGY.

Saline County has within its borders rocks of two widely different geologic ages. The northwestern portion of the county is covered with Paleozoic shales, sandstones, and novaculites, much folded or standing on edge, and intersected by a vast number of quartz veins; while the southeastern part is of soft and usually uncompacted and horizontally bedded Tertiary sands, clays, and gravels, except in parts of T. 2 S., R. 14 W., where eruptive rocks come to the surface. The line separating the Paleozoic and Tertiary areas runs through the county in a northeast-southwest direction. The St. Louis, Iron Mountain and Southern Railway follows the dividing line approximately parallel with and from 1 to 4 miles northwest of it. The region of Paleozoic shales and sandstones to the northwest was the dry land forming the shores during Tertiary times, when the sands and clays that lie to the southeast were being deposited in the waters which at that time covered all southern and eastern Arkansas.

CLAY DEPOSITS.

DISTRIBUTION OF THE CLAYS.

In the northern and western parts of the county pottery clays are not likely to occur in abundance. They may possibly be found in occasional local pockets, where the clay shales have decayed, or in "slashes," where the water has leached out local accumulations; but the great pottery clay beds lie south and east of the old shore line referred to above. In the river bottoms also, especially along Saline River, the immediate surface soil includes here and there "buckshot" clays, which furnish rather poor pottery clays.

CLAYS ABOUT BENTON.

The clay pits opened in the vicinity of Benton have aided a comprehension of both the general and detailed structure of this part of the State. These pits are all in T. 2 S., R. 15 W. The sections which they represent are here given in detail, beginning with the Hicks pit in the NE. ¼ NE. ¼ sec. 12.

HICKS CLAY BANK.

The Hicks clay bank, formerly known as "the old Leach bank," was the first clay deposit opened in the neighborhood of Benton, and for several years was the only source of supply for pottery clays at that place. Early in 1889 the old pit was reopened by Mr. J. Howe, and the clay was mixed with clay from other pits for use in his pottery. It is not used by itself in any of the potteries.

Section at the Hicks pit.

	Feet.
Sandy soil, capped with novaculite gravel	2
Sandy clay, with scattered pebbles; particolored and more sandy below	7
Drab potter's clay	20

The bottom of this clay had not been reached by the operations in progress at the time it was visited. The clay at different points of the pit varies in the amount of sand it contains. It is pinkish brown when first dug, but as it dries becomes light gray with a faint pink tinge. It has a slightly sweetish taste. It is wanting in body and will not burn to a solid stoneware. Only the Albany slip-black glaze can be used with it, all attempts hitherto made at salt glazing having resulted in failure owing to the inability of the ware to bear a sufficiently high heat. When subjected to a white heat it cracks and breaks in the kiln, and the pieces escaping destruction in this way are liable to air check in cooling. It may be very profitably manufactured into open ware, however, such as pots, churns, crocks, and milk pans, or into any article in which the liquid contents are not allowed to stand long. Unglazed ware made from this clay is very porous, and when glazed ware made of it cracks or chips so as to expose the body of the vessel it is found to be very absorbent, so that it can not be employed for ware that is to be used to hold liquids for any great length of time.

THE RHODENBAUGH CLAY BANK.

The Rhodenbaugh bank is in the SW. ¼ NE. ¼ sec. 12, T. 2 S., R. 15 W., about one-fourth mile south of the Hicks pit. A depression between this and the Hicks bank is filled with waterworn gravel.

The sections at the two pits are practically the same, and the beds are the same, but there is a slight difference or local variation in the character of the clays themselves.

Section at the Rhodenbaugh clay bank.

	Feet.
Thin sandy soil with fine gravel	1
Ferruginous gravel with abundant coarse sand; clayey below	5
Light-drab potter's clay, the lower 2 feet of which is blue containing red patches of iron	10
Fine white sand	1½
Novaculite gravels, conglomerated	3
	20½

Below the pottery clay is a bed of brownish-yellow waterworn, novaculite gravel, much of which is cemented into a conglomerate. Near the upper surface or top of the 10-foot bed of clay there is a streak of black material 2 inches thick. The 2 feet of blue clay constituting the base of this bed contain numerous impressions of leaves and stems of plants and red patches. This 2-foot layer of clay is not used in the manufacture of pottery but goes to the waste bank with the gravel. This blue clay might, if mixed with sufficient quantity of sand, be used for the manufacture of bricks. Bricks as a rule do not require the same degree of firing as stoneware, and the red material, if mixed properly, will be an advantage rather than a detriment to it, as it would serve to color the whole mass. This clay is rejected by the potters because the ware must be subjected to a prolonged white heat before it will take the glaze necessary to produce a marketable product, and under the high temperature required the red clay, which is highly charged with iron, would melt or turn black and make the ware unsightly and unfit for market. Great care must therefore be exercised to prevent any of this material from being mixed with the clean pottery clay.

The clay from the Rhodenbaugh bed is fine grained and of close texture. When moist it has a pinkish-brown color, which it loses on drying. Although sometimes used without any mixture the proprietors of the pit consider it very much improved by the addition of a little sand. The sand adds to the body and in burning enables the ware to take a hard finish. It will take either the Albany slip glaze or the salt glaze.

The bed of clay found in Rhodenbaugh's pit covers about 8 acres and thins out toward the south within a short distance of Rhodenbaugh's house.

The following is the section exposed in a well 36 feet deep in Rhodenbaugh's garden, in the NW. ¼ SW. ¼ sec. 12. The well does not strike the clay, although it penetrates the Tertiary and reaches Paleozoic rocks below. The mouth of the well is doubtless at a point below the clay bed.

Section of Rhodenbaugh's well.

	Feet.
Waterworn gravel	12
Black clay, breaking up in flakes	4
Stiff, tenacious blue clay	20
Paleozoic sandstone at the bottom.	
	36

A well is reported to have been dug at Bernard Fiste's place, near the middle of the north side of sec. 13, about three-fourths of a mile east of Rhodenbaugh's pottery. In this well a pottery clay bed was struck at a depth of 45 feet. The bed is said to be 15 feet thick here and of dark color. The clay, which has been tested, retains its dark color after burning. Its occurrence at this place throws much light on the distribution of the pottery clays about Benton.

WOOSLEY CLAY BANK.

The Woosley clay bank is in the NE. ¼ sec. 1, on both sides of "the old military road" leading northeastward from Benton. The clay is 5 or 6 feet thick, but it thins out at the margins of the bed, which covers about 1½ acres. About 400 feet east of Mr. Woosley's house the following section is exposed in an abandoned clay pit:

Section at Woosley's clay pit.

	Feet.
Brown pebbly, iron-stained clay	4
Red sandy clay	6
Blue clay with red patches	2
Pottery clay	5
Grayish sand	4
	21

The following section is reported by Mr. Kennedy:

Section of pit at Woosley's pottery sheds.

	Feet.
Hard grayish sandy clay	4
Pottery clay	5
Light-grayish sand	6
Bluish joint clay at base.	

Mr. Woosley has opened another clay pit on the west side of the SW.¼ NW. ¼ sec. 1. The beds exposed are as follows:

Section in SW. ¼ NW. ¼ sec. 1, T. 2 S., R. 15 W.

	Feet.
Red sandy clay	4
Pottery clay	4

The well section at Woosley's pottery, reported by Call, is interesting as showing the relations of the potter's clay of his pit to the underlying blue joint clays of Eocene age. The section should be considered in connection with that at Womack's pit, in the village of Benton.

Section of well at Woosley's pottery.

	Feet.
Gravelly and clayey sand	4
Potter's clay, becoming sandy below	10
Stratified blue or black joint clay	45

The well ends in the joint clay without penetrating it. Probably the clay is precisely equivalent to that found in the Benton well sections.

The section at Woosley's pit, as observed by Professor Call in June, 1891, is given below.

Section at Woosley's clay pit.

	Feet.
1. Light gravelly and sandy soil	1
2. Gravel bed, with much coarse sand	3
3. Red sandy clay with occasional pockets of clay	8
4. Snuff-colored potter's clay, upper foot containing pockets of red sand, lower 4 feet a bright-yellow potter's clay	12
5. Fine white sand with some clay	12
	36

The sands from No. 5 of this section were mixed with clays from No. 4. The pottery made of this combination was a. well-bodied light-yellow ware with a metallic ring, and took a good glaze. Only a portion of this clay was worked and the pit was then abandoned by its owner, who now uses clay from a bed 500 feet north of Davis's pottery and west of the military road.

In appearance and in general structure the clay taken from Woosley's bed is like that found in the other clay deposits near Benton. It is light pinkish brown when moist and dries to a faint pink color. In working and burning it has the reputation of being, next to that from Rhodenbaugh's bed, the finest clay in the district. It burns to a solid stone body and takes both salt and Albany slip glaze.

DAVIS CLAY BANK.

The L. R. Davis pit (formerly Herrick & Davis) is in the NW. ¼ SE. ¼ sec. 2, on the northwest side of the old military road. The following section in a pit near the west end of the bank shows the relations of the several beds:

Section at the L. R. Davis clay pit.

	Feet.
Waterworn gravel	3
Red clay	4
Potter's clay	11
Ferruginous sandstone at the bottom.	

Nearly the same section is exposed in a well 50 feet deep a little east of the east end of the pit. In the well section the gravel is thicker and the red clay somewhat thinner, while the potter's clay remains the same.

Below is given the section of a well at Mr. Herrick's house, east of Davis's clay pit, in the NW. ¼ SE. ¼ sec. 2, T. 2 S., R. 15 W.

Section of Herrick's well.

	Feet.
Waterworn gravel	4
Brown pottery clay	11
Coarse, white, sharp sand	25
Waterworn, iron-stained gravel	10
	50

The potter's clay thins out and disappears south of the road and about 50 yards south of Davis's pottery sheds. The clay burns to a white or cream color and may be glazed by both salt and Albany slip glaze.

HENDERSON CLAY BANK.

S. M. Henderson's bank is in the NW. ¼ NE. ¼ sec. 2, T. 2 S., R. 15 W., and underlies a brownish sandy gravel 3 feet in thickness and a blue sandy clay containing bright patches. This sandy clay is of variable thickness, but it averages about 3 feet. Beneath this bed lies the potter's clay, with a thickness of 14 feet. The color of the clay varies with the depth in the pit, ranging from light blue or pinkish on top to almost black at the base. The lower strata contain impressions of leaves and stems of plants. This clay burns to a stone body that readily takes both the Albany slip and the salt glaze.

About 300 feet east of Kirkpatrick's house a well at his brickyard shows the pottery clay to have a covering of 15 feet.

At Kirkpatrick's, on the west side of the NE. ¼ NE. ¼ sec. 11, a well 20 feet deep penetrates gravelly, sandy clay and ends in the potter's clay beds.

This bed is probably continuous eastward over the bottoms along the creek. Its dip is southeast, as is indicated by the occurrence of a similar bed in a well section three-fourths of a mile farther east, in the NE. ¼ NE. ¼ sec. 23, T. 2 S., R. 15 W., which is without doubt an extension of the same deposit.

Search has been made for these beds at various points in ravines and gullies along the hillside south of the Iron Mountain Railway depot at Benton, but none were found.

WOMACK CLAY BANK.

A stiff, dark, lead-colored clay appears in the town of Benton on the west side of Market street and between that point and the "old military road," in the NW. ¼ SW. ¼ sec. 11, T. 2 S., R. 15 W. The clay is at least 30 feet thick, as seen in the section given below (by Call), but its total thickness has not been ascertained. It gets darker as it is penetrated deeper.

Section at Womack's clay pit, Benton.

	Feet.
Soil, sandy and gravelly	2
Gravel and coarse sand, highly ferruginous	6
Conglomerate; sand and fine gravel cemented with iron oxide	½
Blue or lead-colored joint clay, with scattered nodules of iron pyrites	30½
	39

The clay found in this pit occurs in the bottom of a dozen or more wells in the village of Benton. A well digger who had put down nearly all these wells exhibited a mass of clay from the bottom of one well (which stratum he said was reached in all wells attaining a depth of 40 feet or more) containing marine shells (*Turritella carinata*) of Eocene (Tertiary) age.

In certain portions of the pit, near its middle line, occasional nodules of iron pyrites occur. Mica scales abound in the cleavage planes and rarely crystals of selenite are seen.

The clay from Womack's pit is too stiff to be worked in ordinary pugs, and must be crushed by special machinery. A sample brought to the office of the Arkansas Geological Survey by Mr. Womack was somewhat streaked with iron, some of which seems to have infiltrated along the rootlets of plants.

This clay taken alone is not a distinctively good potter's clay, and ware made from it is not equal to that made from the clays of any other Benton pit. It gives a heavy body and cool cracks when salt glaze is employed. It is mixed with clay from Hicks's pit in the proportion of equal parts of each, and in this way makes a very fair gray pottery. It is highly probable that with some experimenting a method could be hit upon that would make it possible to utilize this fine bed of clay to better advantage. If no better use be found, it might be available for making vitrified bricks.

OTHER CLAYS NEAR BENTON.

In the southeast corner of the SW. ¼ NW. ¼ sec. 13, T. 2 S., R. 15 W., near Mrs. Butler's house, a well 65 feet deep passes through a bed of dark potter's clay 30 feet thick.

Section of well near Mrs. Butler's.

	Feet.
Red clay	4
Sand	24
Potter's clay	30
Waterworn gravel	7
	65

In the NW. ¼ SW. ¼ sec. 13 a well 800 feet south of Mrs. Butler's, just west of the road, is 20 feet deep but does not penetrate the potter's clay bed. The mouth of this well is about 15 feet above the mouth of Mrs. Butler's well.

Section in sec. 13, T. 2 S., R. 15 W.

	Feet.
Red sandy clay	3
Joint clay	4
Blue sand	13
	20

In the NE. ¼ SE. ¼ sec. 13, T. 2 S., R. 15 W., at Bennett's pottery, a well 20 feet deep has the section given below.

Section of well at Bennett's pottery.

	Feet.
Soil	5
Clay	2
Red sandy clay	12
Blue sand at bottom.	

The well section at Mrs. Butler's and at other points south of the railway, taken in connection with the other observations, throws light on the distribution of the clay beds about Benton and throughout the region south of Benton. The relations of these sections to one another can be best shown by the profile given in fig. 16. This section shows why pottery clay was not found either in the well south of Mrs. Butler or in that at Bennett's pottery. If these wells were carried down 25 feet deeper they would enter the bed penetrated at Mrs. Butler's.

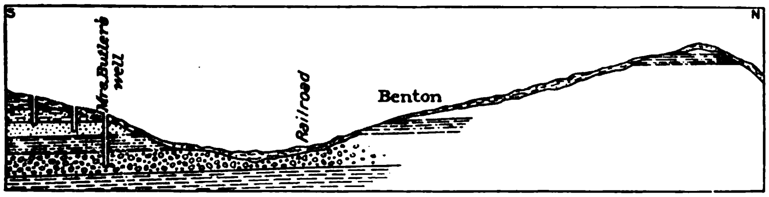

FIG. 16.—North-south section at Benton, showing relations of the clay beds north of the railway to those south of it.

On the hills west of Mrs. Butler's, at a point in the W. ½ sec. 14, but not precisely located, a well is reported with the following section:

Well section in sec. 14, T. 2 S., R. 15 W.

	Feet.
Clay and gravel	10
Clay with sand streaks	20
Sand	4

It seems probable that the sand found in the bottom of this well is the top of the sand bed that overlies the potter's clay, and that if the well were carried down 20 feet deeper it would enter the clay.

Mr. T. C. Hopkins also found an exposure of weathered potter's clay on the south side of the little stream about a quarter of a mile south of the Benton depot. This is about where one would expect to find the outcrop of the great bed on the south side of the valley.

The elevations were observed (by aneroid barometer) at Mrs. Butler's and at the various clay pits north of the railway for the purpose of determining whether the clay pits were all upon the same bed, and to ascertain the dip of the beds.

Elevations of the pottery clay beds near Benton.

	Feet.
Rhodenbaugh's pit	340
Hicks's pit	350
Davis's pit	420
Woosley's pit	440
Bed in Mrs. Butler's well	325
Bennett's pottery	340
Henderson's pit	380

These elevations show that the beds have a gentle dip to the east and south and that the Rhodenbaugh, Hicks, Davis, Woosley(?), and Henderson pits on the north side of the railway track are in all probability on a bed of clay identical with the bed cut in Mrs. Butler's well. The slight differences of the clays found in the various pits are of a character that usually occurs in any deposit in passing from one point to another. The thinness of the beds and their irregularities are no doubt produced by the greater erosion to which the northwestern or landward edges of these soft beds have been exposed.

The Woosley bed appears to be higher than the others and to be only the small fragment of a bed which once overlay the region south of Woosley's, but which has all been removed by erosion except this remnant and its possible southward extension, which is to be looked for in the hilltops south of Mrs. Butler's well.

The beds opened north of the railway (except Woosley's) appear to be all parts of the same deposit, and in all probability the clay may be found in a long outcrop that will connect the Hicks, Henderson, Davis, and Rhodenbaugh banks with the well at Mrs. Butler's.

The sections and records given above relate only to the beds exposed in the immediate neighborhood of Benton. Most of the clays of these beds have been tested in one way or another. There is no reason for supposing that the valuable clay beds are confined to this locality, but the geology leads us to conclude that just as good deposits exist in other parts of the county. With a view to ascertaining as much as possible regarding the distribution of the potter's clays in the surrounding country the following observations are brought together here:

About the center of the SE. ¼ SE. ¼ sec. 3, T. 2 S., R. 13 W., there is a bed of clay on Robert Bigg's place that deserves special attention. The geologic observations at this locality were kindly furnished by Mr. E. C. Buchanan, of Little Rock, who made two trips to examine it, and who collected the sample whose analysis is given below. The clay outcrops at several places in the SE. ¼ SE. ¼ sec. 3. The outcrops are in a series of small gullies, from 2 to 7 feet deep, draining south and southeast and northeast. The section exposed is as follows:

Section at the Robert Bigg place.

	Ft.	In.
1. Sandy clay and gravel	2	6
2. Reddish clay	2	
3. Cream-colored clay	5	
4. Reddish sandstone		½
5. Cream-colored clay	10	

Mr. Palmer, who lives at the northwest corner of SE. ¼ sec. 3, says that he dug a pit 3 feet at the lowest part of the exposure of No. 5 without reaching the bottom of that bed. The beds seem to be horizontal.

The clay of the bottom bed (No. 5) has a conchoidal fracture, and is cream colored when first dug out, but on exposure to the sun it becomes nearly white. Beds of No. 3 and No. 5 are apparently about the same, but are separated by the thin layer of sand rock.

A well 55 feet deep, dug by Mr. Palmer at the point indicated, starts about 20 feet below the level of the clay and for that reason does not penetrate the bed. The clay is thus confined in this locality to the tops of the low hills, and the total area underlain by it here is about 20 acres. It is probable, however, that the same bed occurs in the surrounding hills, especially toward the east. The same bed is exposed at the spring just south of Mr. Bigg's house, where fragments of lignite overlie it.

The composition of No. 5 of the section at Robert Bigg's place (SE. ¼ SE. ¼ sec. 13, T. 2 S., R. 13 W.) is given below.

Analysis of clay from the Bigg place.

[L. R. Lenox, analyst.]

Silica (SiO_2)	63.29
Alumina (Al_2O_3)	18.19
Iron (Fe_2O_3)	6.45
Lime (CaO)	.31
Magnesia (MgO)	2.44
Manganese (MnO)	Trace.
Potash (K_2O)	.56
Soda (Na_2O)	Trace.
Water (loss on ignition)	9.47
	100.71

In the low ground about 2 miles southwest of Alexander, on the St. Louis, Iron Mountain and Southern Railway, potter's clays of a buff color are exposed in the ditch by the railroad. This exposure is at the foot of the railroad grade that descends from the summit next north of Bryant to Crooked Creek, and is 1¼ miles from Bryant. Again, potter's clay is reported on the railroad near Bryant, a short distance southwest of the station. The well sections at Bryant, however, do not show satisfactorily that such clays exist there. The well at the Commercial Hotel, about 50 paces south of the railroad, and 22 feet deep, has hard clay in the bottom, but it is not known whether it is a potter's clay. Another well, 22 feet deep, a quarter of a mile northeast of the station, has lumpy clay in the bottom, but it is probably not a good potter's clay. In the NW. ¼ sec. 24, T. 1 S., R. 15 W., a well 15 feet deep has 10 feet of pipe clay in the bottom. Nothing is known of its value. In the SE. ¼ sec. 13, same township, a well 30 feet deep has 10 feet of "joint clay" in the bottom.

At Zuber post-office, in the NE. ¼ sec. 5, T. 1. S., R. 15 W., there are two wells. One in a depression struck black shale 4 feet below the surface, and one on the slope above the sawmill struck black shale at a depth of 20 feet. In the débris from the latter are numerous lumps of potter's clay, resembling that at Benton.

In the NE. ¼ NW. ¼ sec. 36, T. 2 S., R. 16 W., at Mr. Cliff's, a well passed through the following section:

Section of Cliff's well.

	Feet.
Red clay and sand	4
Clay with fossil shells	20
Decayed limestone	2

The clay referred to was not seen by the writer, but it is possible that a portion of the bed, at least, may be available for pottery.

Clay beds, somewhat mottled on their exposed surfaces, occur in the NW. ¼ SW. ¼ sec. 19, T. 2 S., R. 15 W., but the Paleozoic rocks are exposed on the lower side of the hills that slope to the north in this quarter section. In the SW. ¼ sec. 20, of the same township, a well 25 feet deep penetrates beneath the topmost 4 feet an 18-foot bed of light-colored potter's clay containing streaks of sand near the bottom.

A well 40 feet deep in the middle of the east side of sec. 3, T. 3 S., R. 16 W., is said to be dug entirely in red and white pipe clay, through which there is a single black streak. No evidence was found of clay farther south in Saline County than where it is cut in this well. It should be remarked, however, that no well sections were found farther south. The surface is covered with fine quartz and novaculite gravel, which seems to form the slope of the hill on the south side of the small creek in sec. 10, T. 3 S., R. 16 W. In the NE. ¼ sec. 14 of this township 16 feet of clay is also reported in a well. This is in Hot Spring County.

Between the county line and Traskwood and thence northward on the Traskwood-Benton road for more than 4 miles the well sections show only sand or very sandy clays.

On Crooked Creek in the SW. ¼ NE. ¼ sec. 15, T. 1 S., R. 14 W., about three-fourths of a mile west of Collegeville, there is an exposure of blue, white, and variegated shales.

Section on Crooked Creek.

	Feet.
1. Surface gravel and humus	3
2. Sandstone	1
3. Blue and white shales having a talcose or soapy touch	2
4. Light-colored shales, drying white and chalky	1
5. Blue clay.	

All these shales have a greasy feel and very much the same appearance in fracture and splitting. No. 4 of the above section was analyzed with the results given below.

Analysis of shale from Crooked Creek.

[Brackett & Smith, analysts.]

Silica (SiO_2)	82.45
Alumina (Al_2O_3)	11.80
Iron (ferric) oxide (Fe_2O_3)	.80
Lime (CaO)	.31
Magnesia (MgO)	.25
Alkalis (by difference)	1.60
Water (loss on ignition)	2.79
	100.00
Water at 110°-115° C	.21

The air-dried material contains 27.37 per cent of fine sand.

The following table brings together the analyses of all the pottery clays examined from the different clay banks at Benton, except that called kaolin on pages 196-197.

Analyses of clays from Benton, Saline County.

	Rhodenbaugh.	Davis.	Henderson.	Hicks.	Woosley.	Womack.
Silica (SiO_2)	72.44	69.95	71.09	65.79	64.49	66.23
Alumina (Al_2O_3)	18.97	22.34	19.86	23.92	23.86	22.31
Iron (ferric) oxide (Fe_2O_3)	1.59	1.44	1.81	1.94	2.11	2.12
Lime (CaO)	.18	Trace.	.11	.23	.31	.92
Magnesia (MgO)	Trace.	.08	Trace.	Trace.	Trace.	Trace.
Potash (K_2O)	1.35	1.28	1.45	1.15	.11	.04
Soda (Na_2O)	.91	.18	.81	1.08	1.82	1.59
Water (H_2O)	5.39	5.98	5.67	7.07	8.11	7.38
	100.83	102.25	100.80	101.18	100.81	100.59
Water at 110°-115°C	1.55	2.34	1.96	1.80	2.37	7.27
Sand	.26	.46	3.13	2.72	.19	....

GENERAL CONCLUSIONS.

That Benton is well supplied with excellent clays for the manufacture of the common grades of stoneware and pottery is a fact established by the experience of many years. The clays there used, however, have a much wider distribution throughout the southern and eastern parts of the county than seems to be suspected. They have been found at Bernard Fiste's place, west of Rhodenbaugh's pottery, while the great bed cut in Mrs. Butler's well in sec. 13, T. 2 S.,

R. 15 W., is simply the southward continuation of the beds opened north of the railway. The bed extends around the hills to the south, the outcrop being in the faces of the hills that look toward Saline River. It is exposed on nearly all the hillsides on the old military road running northwestward from Benton, probably extending to and beyond the borders of the county.

In the broad bottoms on the west side of Saline River the "buckshot clay" lies beneath the surface soil and good clays are not to be expected here in such localities within easy reach.

The Tertiary hills west of the Saline begin about the middle of the SE. ¼ sec. 20, T. 2 S., R. 15 W. The Tertiary clays encircle these hills north of the railway and west of the river, and the potter's clays will probably be found about the bases of these hills in the vicinity of Traskwood, on both sides of the railway. The geology of the region favors the supposition that the potter's clays occur also within the drainage of Hurricane Creek, in the southeastern part of the county.

Those who are in search of pottery clays in Saline and adjoining counties should bear in mind that such clays are at many places associated with leaf and other plant impressions and not often associated with marine shells. Many of the Saline County clays that are now regarded as but poorly or not at all adapted to the manufacture of common pottery need only more careful study and experimenting to make them available. That a clay can be used unmodified, just as it comes from the pit, is a mere accident, and while it is a fortunate one, we should not be satisfied to allow an industry to depend on it.

VARIETIES OF KAOLIN.

SALINE COUNTY KAOLIN.

The syenite area of Saline County lies in secs. 35 and 36, T. 1 S., R. 14 W., and in secs. 1, 2, 9, 10, 13, 14, 15, 16, 20, 21, 22, 23, 24, 25, 26, 27, 34, and 35, T. 2 S., R. 14 W. The margins of the crystalline rocks are covered by the Tertiary and Pleistocene deposits, which make up the remainder of the county southeast of the railway in Saline County.

The kaolins found in Saline County are of three varieties—(1) a compact variety, derived directly from feldspathic rocks by decomposition; (2) a pisolitic variety, found associated more or less intimately with the bauxite deposits, and (3) a claylike variety of sedimentary origin, found at Benton.

The first two of these varieties are not readily separable and will here be considered together.

COMPACT AND PISOLITIC KAOLIN.

Kaolin exists in secs. 9, 10, 14, 15, 16, 21, 22, 23, 26, T. 2 S., R. 14 W., and probably in other places. The deposits in sec. 16 seem to be extensive, for kaolin is found here and there almost all over that section. In the SE. ¼ SE. ¼ sec. 16, T. 2 S., R. 14 W., it is exposed on the eastern side of a ridge, where it rests on syenite. This deposit has never been bored through and its thickness is unknown. Messrs. Nethercut, the proprietors, have quarried it on a small scale for building material. The coarser matter is used for building the outsides of chimneys and the finer is employed for lining flues and hearths. In carrying on these quarrying operations the material was penetrated to a depth of 15 feet near the upper edge of the deposit, but the kaolin had not been passed through.

In the NE. ¼ SW. ¼ sec. 16, 80 or 100 yards west of Mr. Sol. Nethercut's house, an excavation 8 feet in diameter and 15 feet deep was made for the purpose of testing the thickness of the kaolin, but the undertaking was abandoned before the bed was cut through. At Mr. Sol. Nethercut's house, near the northwest corner of the NW. ¼ SE. ¼ sec. 16, a well 18 feet deep shows a face of 10 feet of kaolin in the bottom of the well. This does not indicate the thickness of the deposit at this place, as the digging was stopped before the kaolin was penetrated.

Kaolin also overlies the syenite at many places in the SW. ¼ SE. ¼ sec. 16, T. 2 N., R. 14 W.

On the north side of the NE. ¼ sec. 16 there is a large deposit of kaolin which extends across the line into sec. 9. This kaolin varies somewhat in appearance in different positions. That on the eastern side of the SE. ¼ SE. ¼ sec. 16 is of two kinds. One bed is white or grayish white, having small specks and streaks of a gray material scattered through the white ground and occasional patches of iron stain. The other contains fewer gray patches, but is of a pale pinkish or brownish tint. The pink-tinted kaolin generally overlies the gray mottled material.

The deposits on the bank of the stream in the NE. ¼ SW. ¼ sec. 16, as well as those in the diggings and wells in this division of the land section, have generally a white, chalky appearance. It does not show so much iron staining or gray specks as the material found in the SE. ¼ SE. ¼. sec. 16.

The deposit found in the NE. ¼ sec. 16 and the SE. ¼ sec. 9 is a white and gray streaked material very similar to the lower gray-streaked bed in the SE. ¼ SE. ¼ sec. 16.

Analyses of kaolins from sec. 16, T. 2 S., R. 14 W.

	NW. ¼ SE. ¼.	SE. ¼ SE. ¼.
Silica (SiO_2)	45.62	44.97
Alumina (Al_2O_3)	34.18	38.87
Iron (ferric) oxide (Fe_2O_3)	4.05	1.34
Lime (CaO)	.20	.25
Magnesia (MgO)	Faint trace.	Faint trace.
Potash (K_2O)	.53	.20
Soda (Na_2O)	.54	.34
Manganese (MnO)	.17	Strong trace.
Water	13.82	14.37
	99.11	100.34
Water at 110°-115° C	1.46	5.51

The distribution of pisolitic kaolin in this district is probably nearly the same as that of bauxite, and the map accompanying Dr. C. W. Hayes's report on Arkansas bauxite[a] shows the distribution of bauxite and of crystalline rocks in Saline County so far as they are known. As in the other bauxite areas, the pisolitic kaolin is to be sought well below the surface, where it is probably of better color, softer, and freer from iron than nearer the surface.

TERTIARY KAOLIN AT BENTON.

Beds of kaolin that are formed by the decomposition of feldspar are commonly irregular and pockety in form, owing to the irregularity with which the feldspathic rocks decay. After the rocks have decomposed, however, the kaolin is liable to be washed away, and when it settles to the bottom of a body of water it will be spread out in horizontal beds like other sediments. It seems probable that some, possibly all, of the sedimentary kaolins are formed in this way.

At Benton two beds of kaolin are associated with the Tertiary deposits. One of these is exposed on the north side of the stream in the SW. ¼ SW. ¼ sec. 36, T. 1 S., R. 15 W., on the slope of a hill about 600 feet northwest of Howe's pottery and at intervals along the face of the hill for several hundred feet. It is about 9 feet thick and looks like a firm white clay. Above it is 6 feet of coarse, indurated red sand, and above this is a thin sandy soil.

The association of this bed with the pottery clays and its attractive appearance have led to attempts to utilize it for making the ordinary coarse pottery usually manufactured at Benton, but as it requires treatment different from that given the common pottery clays, its use for this purpose was soon abandoned.

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[a] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, Pl. LXI.

Analysis of Tertiary kaolin from Benton.

[R. N. Brackett, analyst.]

Silica (SiO_2)	48.34
Alumina (Al_2O_3)	34.58
Iron (ferric) oxide (Fe_2O_3)	1.65
Lime (CaO)	.81
Magnesia (MgO)	Trace.
Potash (K_2O)	.44
Soda (Na_2O)	1.26
Loss on ignition (water)	12.94
	100.02
Water at 110°-115° C	2.20

It is to be hoped that other efforts will be made to turn this bed of kaolin to account. It should be remembered that no kaolin can be used just as it comes from the pit; each one requires a treatment of its own, and he who experiments with this variety until he understands how to treat it will probably be well rewarded for his trouble. It must not be expected, however, that a kaolin that contains so high a percentage of iron will burn white. If mixed with a poor sandy clay it will probably make an excellent pottery clay.

CLAY INDUSTRY.

Eagle Pottery Company.—The plant of the Eagle Pottery Company is located 1½ miles northeast of Benton. It has a capacity of 800 to 900 gallons daily. Four turners are employed, some of whom turn 300 gallons a day. Twenty-two pounds of clay are used in a 5-gallon vessel and 6½ pounds in a 1-gallon vessel. The smaller the vessel the more clay is used per gallon.

The ware is burned in a rotary up-draft kiln. Forty-eight hours are required to burn the ware. Twelve cords of wood, mostly pine, are used to each kiln.

The principal vessels made are jugs, crocks, jars, and churns, which contain from 1 to 5 gallons each. The unglazed ware burns to a beautiful light buff color. Arkansas slip is used.

The clay used by this factory is obtained in two places. The purest and best clay comes from a pit on the roadside one-half mile south of the kiln, between the kiln and Benton. When fresh the clay has a chocolate color, but becomes white when dry. It is plastic, free from grit or sand, and very similar in appearance to the clay from Holly Springs, Miss. It occurs in large lenses and is overlain by Lafayette sands and gravel, which in places rest directly on the clay. In some places the stratified sands of the Tertiary intervene between the clay deposits and the Lafayette. The clay, therefore, belongs to the older Tertiary sands and not to the Lafayette. Leaf impressions in the clay are reported to be of frequent occurrence.

The second locality from which clay is obtained is at the pottery. This is a dark-blue stratified clay containing more or less sand. An equal amount of clay from the two localities is used in making the ware.

Benton Brick Manufacturing Company.—Bricks are made by the Benton Brick Manufacturing Company from a surficial deposit that lies above the Lafayette gravel beds. It is a very sandy brick clay composed of about one-third clay and two-thirds sand. The clay is hauled from the pit to the pug mill in wheelbarrows. The pug mill is run by horse power. The bricks are molded in a hand mold and taken to a shed, where they are dried in air without artificial heat. When the bricks are sufficiently dried they are wheeled to a rotary up-draft kiln and burned. The plant employs eight men and has a capacity of 5,000 bricks a day. Five days and nights are required to burn the brick and 20 cords of wood are used to the kiln—10 cords of pine and 10 of oak. The clay makes bricks of poor quality.

SCOTT COUNTY.

GENERAL GEOLOGY.

The geology of Scott County is like the geology of those parts of Sebastian County that lie below the coal. The coal-bearing beds enter Scott County only through the parts occupied by the Poteau Mountains. So far as the clays alone are concerned, however, the coal is of but little importance, for there is an abundance of excellent clay shale in the rocks below the coal.

The rocks of Scott County are all more or less folded, and the denudation that has removed much of them has left the usual ridges of sandstone dominating the valleys cut in the shales.

In the northern part of the county there are long, winding sandstone ridges with shale valleys parallel to them. Coops Prairie, already mentioned under Sebastian County, is half in Scott County, Coops Ridge swinging around the east end of it. Bluff Ridge, starting a mile south of the eastern end of Coops Ridge, runs a little north of east for 4 miles, to the toll bridge, then turns northward for 2 miles, and then swings eastward, crosses Washburn Creek one-half mile above the point where that stream enters Petit Jean Creek, and thence continues eastward and southward until it goes nearly around Jennings Hill. Between Jennings Hill and Bluff Ridge there is another ridge of sandstone that completely encircles Jennings Hill, though it is twice cut by Petit Jean Creek.

These ridges of sandstone are mentioned only for the purpose of directing attention to the shale beds that accompany them, for the valleys between are made up for the most part of shales which are here argillaceous and there sandy. Washburn Creek, just north of Pine Log Ridge, in the extreme northern end of Scott County, flows along one of these shale valleys. East of the mouth of Washburn Creek this same shale valley continues past Barber post-office into Logan County. South of Pine Log Ridge another long but narrow valley crosses this end of the county. Still farther south is Bluff Ridge, already mentioned. The valley south and east of Bluff Ridge is a remarkable one. Geologically it begins on the headwaters of Little Petit Jean Creek, southwest of the toll bridge, passes northward by way of Crow post-office, then turns eastward to the mouth of Washburn Creek, extends down Petit Jean Creek to the point where it cuts through Bluff Ridge, and there swings southward and westward past the town of Belva. Here it forks, one part passing westward toward Crow, the other swinging southward and eastward, where it runs along the north base of the Poteau Mountains. Everywhere throughout this valley are shales, some of them clay shales and others more or less sandy. Another shale valley runs completely around Jennings Hill.

The Poteau Mountains themselves are made up of shales and sandstones that are higher in the geologic series than the rocks of the lower lands both north and south of them. Near the base of the southern slopes of Poteau Mountain there is a series of parallel ridges and valleys. These ridges are of sandstone again and the valleys between are in shales. Beginning at the Indian Territory line in sec. 31, T. 3 N., R. 32 W., one of these shale valleys passes just north of Gipson post-office and just north of the town of Cauthron, and so on eastward to the valley of Self Branch, 5 miles north of the town of Waldron. South of the Poteau River the region both north and south of Walker Mountain is made up of a series of sandstone ridges and shale valleys. The sandstones predominate here, however, and the shales do not form such thick beds as they do north of the Poteau Mountains or in the region about and south of Waldron.

The town of Waldron stands in a broad shale valley which passes 4 or 5 miles east of the town and then bends northward and westward and swings back so as to form one of the set of valleys parallel with Poteau Mountain along its south side. A mile south of Waldron is a sandstone ridge that extends a few miles farther west and bends northward, ending in a low, hooked ridge about 2 miles west of the town. East of Waldron this same ridge continues for several miles along the north side of the upper part of Poteau Creek. South of this sandstone ridge is a broad shale valley through which runs Haw Creek and the headwaters of Poteau Creek. South of this is a series of parallel ridges of sandstone, the most prominent of which are Piney Mountain and Ross Mountain. The shales interbedded with these sandstone beds are not very thick, but many of them are available for the manufacture of clay goods. One of the most prominent of these valleys is that along which Ross Creek flows. This is a shale valley about 11 miles in length.

CLAY DEPOSITS.

Over the whole of the valley regions of Scott County ordinary brick clays occur in the form of loam or buckshot clays. In many places this brick loam is from 2 to 6 feet thick. It is often high in iron, however, and the brick made of the clays containing much iron are likely to be covered with dark brown or black spots, and the bricks as a whole usually have a dark color. These clays are especially abundant in the upper bottom lands of Poteau River, from the point where it enters Oklahoma up to and east of Waldron. They occur also along Black Fork of Poteau, along Ross Creek, and in the broader parts of the valley of Fourche La Fave River. North of Poteau Mountain similar clays are found in the upper bottoms of all the streams, but especially in those of Petit Jean Creek and its principal tributaries, and along Little Washburn Creek.

No establishments of any kind in Scott County are engaged in the manufacture of clay products.

SEBASTIAN COUNTY.

CLAY DEPOSITS.

CLASSES OF DEPOSITS.

So far as the actual development of the clay manufacturing interests are concerned Sebastian is one of the most important counties in the State. This development could not have taken place, of course, if the geology of the county had not been favorable to the building up of the clay industries; but the fact should not be overlooked that so far as geology alone is concerned several counties in the State are as well provided with valuable clays and clay shales as is Sebastian County.

The geologic structure of Sebastian County admits of clays and clay shales occurring (1) as shales in place in the uplands of all parts of the county; (2) as residuary clays in the uplands derived by disintegration from the Paleozoic shales; (3) as clays in the "second bottoms" or the elevated Pleistocene terraces that follow the general course of the river bottoms; (4) as clays in the alluvial deposits of the river bottoms.

SHALES.

The rocks of Sebastian County all belong to the Carboniferous, except the clays and alluvial deposits along the Arkansas River bottoms. There is but little variation in the older rocks of this county. They consist of sandstones, shales, fire clays, and coal. It has already been pointed out in the chapter on general geology that the sandstones and shales were originally deposited in water as horizontal beds of sediments, and that vegetation growing in marshes afterwards became coal. Subsequently all these beds have been pressed into folds, lifted into dry land, and in many places worn away.

The sandstones are in some places coarse enough to be considered grits or conglomerates, while the shales in places grade over through sandy shales to fine sandstones. The coal is confined to the upper portion of the Carboniferous rocks in Sebastian County, but the clay shales cover a larger area than the coal.

The sequence of the rocks varies from place to place owing partly to the fact that the folding and erosion of the beds has left one set of beds at the surface at one place and another set at another. Moreover, the horizontal variation of the beds or the grading of fine sediments into coarser ones results in a variation in the sequence of the beds, especially when the sections considered are several miles apart.

In the process of denudation (the weathering and breaking up of the rocks and their removal by streams) the shales decompose, readily forming clays, while the sandstones, as a rule, are more resistant. The result is that the valleys are usually cut in the shales, while the sandstones are left capping the hills if the beds are horizontal or forming long winding ridges if the beds are folded. In Sugar Loaf Mountain and in Jennings Mountain the beds are nearly horizontal, and these mountains are capped with sandstone, while in the long, narrow ridges, like Long Ridge, just north of Jenny Lind; Sand Ridge, running from Hackett City to Greenwood; Nigger Ridge, southwest of Huntington, and Devils Backbone Ridge and the other parallel ridges south of Greenwood, the resisting beds are sandstones that have been thrown into folds and then eroded. Inasmuch as the clay shales are interbedded with the sandstones the valleys curve with and follow the ridges, and it is in the valleys that the shales are usually found. At some places the shales are decomposed into soft, plastic pottery clays, as noted later, but more frequently they are compact, or fissile, breaking up under the influence of the weather into small, angular fragments.

One of the most important manufacturing interests of the State is based on the clay shales of the coal-bearing rocks of Sebastian County, which are used in the manufacture of paving bricks. This industry began under circumstances not without interest. In 1889 the citizens of Fort Smith had under consideration the paving of their streets, and the State geologist of Arkansas received a letter from Harry E. Kelley, the chairman of the paving committee, asking his advice in regard to the best clay of the region about Fort Smith for the manufacture of paving bricks. The State geologist visited Fort Smith and examined the clays and clay shales near that city. He found that attempts had been made to manufacture paving bricks from the sandy clays and loams of the river terraces, but these bricks were, of course, too soft to be available for paving streets. It was pointed out to the committee that the clay shales in the vicinity of the city were well adapted to the manufacture of paving bricks. This opinion was supported by analyses made by the State Geological Survey, and later by practical tests made by brick manufacturers.

The following letter was addressed to the paving committee after the examination:

DEAR SIR: At the request of the paving committee of your board of commerce I have made a cursory examination of the material in the immediate vicinity of Fort Smith with a view to ascertaining its availability for the manufacture of paving brick.

The clays and clay shales about Fort Smith available for the manufacture of bricks, tiles, pottery, etc., belong to two distinct geologic ages. To the newer division belong the yellowish, reddish, and dove-colored loams, clays, and sandy clays which underlie almost all the plain upon which the city of Fort Smith is built.

The bricks now made at Fort Smith are made either from the uppermost of these beds or from a mixture of this and the one just beneath it, as is now practiced at Pendle & Morrison's brickyards.

In some of the deeper hollows there are later deposits of chocolate-colored clay which by the admixture of organic matter has been changed to a deep black soil at the surface. An analysis of a similar clay from near Dardanelle is given below.

The other class of material which is available for the manufacture of pottery, bricks, tiles, etc., is a clay shale belonging to the Carboniferous series of rocks. These shales are interstratified with sandstones and other rocks of the coal measures and are probably widely distributed through Sebastian and adjoining counties. The clay said to have been taken from Crawford County to the brickyards of Pendle & Morrison for testing is simply a disintegrated clay shale. The light-colored and mottled clays overlying the sandstones of Harding & Boucher's quarry, a couple of miles south of Fort Smith, are also disintegrated clay shales. An extensive exposure of such shales, however, occurs much nearer the city. On the public road leading south from Fort Smith and about 600 feet south of the crest of what is popularly known as Nigger Hill the ditches beside the road have exposed a thickness of 10 or 15 feet of friable clay shales. This shale bed is capped by a stratum of sandstone, but its base is not exposed. It will be found to extend around the hills on both sides of the road, and there can be no question of its great abundance both at the locality mentioned and in the continuation of the bed around the sides of the hills.

Following is an analysis of the clay shale from Nigger Hill, in the vicinity of Fort Smith:

Analysis of clay shale from Nigger Hill.

[Specimen dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	58.43
Alumina (Al_2O_3)	22.50
Ferric oxide (Fe_2O_3)	8.36
Lime (CaO)	.32
Magnesia (MgO)	1.14
Potash (K_2O)	2.18
Soda (Na_2O)	1.03
Sulphur (S)	.16
Loss on ignition	6.87
	100.99
Sand in air-dried specimen	25.72
Water at 110°-115° C	3.37

The clay shales spoken of as cropping south of the city would, of course, have to be ground before they could be used for the manufacture of either pottery or bricks, but in view of the nature of these clays, the ease with which they can be dug and ground, and the extent of the beds, it would seem very desirable that thorough practical tests should be made of this material and of its availability for making pottery, tiles, retorts, fire bricks, and paving bricks. It will doubtless be found necessary to mix with this material a certain proportion of the sandy clays so abundant all about Fort Smith, but a practical brickmaker can readily determine these proportions by a few trials.

I do not think there can be any doubt about the formations spoken of above furnishing excellent material for the manufacture of paving bricks, pottery, tiles, etc. * * *.

Trusting that these clays and clay shales may receive from our citizens the attention to which they are justly entitled, I remain,

Very respectfully,

J. C. Branner, *State Geologist.*

The analyses showed the shales to be available for the manufacture of paving bricks, and practical tests bore out these results and predictions.

Samples of the shale were also sent for testing to the Brick and Terra Cotta Manufacturing Company, of St. Joseph, Mo., and the results obtained were favorable.

Specimens were also taken from the property of the Oak Park Land Company in the SE. ¼ NW. ¼ sec. 35, T. 9 N., R. 32 W., and shipped for testing to the Tennessee Brick Manufacturing Company, at Memphis. The following letters were received by Mr. May in regard to these tests:

Memphis, Tenn., *August 10, 1889.*

N. May, Esq.: In regard to the manner in which the bricks were made from the samples of Fort Smith clay or shale, will say: Each sample was separately pulverized, pugged, and molded by hand, the oldest and most crude method known for making bricks. With proper appliances for making and burning it would produce a brick not surpassed anywhere in the country for strength and durability and suitable for any purpose where the best bricks are required. It will admit of rapid drying without cracking.

Very truly, yours,

Harry McCue, *Superintendent.*

Memphis, Tenn., *August 13, 1889.*

Mr. Noel May.

Dear Sir: The tests that I have made of the new Fort Smith brick show very excellent results. The samples made of mixed clay are the best. The unmixed-clay samples are very good building brick, suitable for sewers and foundations, strong, dense, and heavy. They will be durable in any position.

The samples made of mixed clay, the two kinds being combined in about equal quantities, show remarkable strength and toughness. I made the percussion test on three samples and at the same time on one of the West Virginia brick, same as we used on North and East Court streets. The Fort Smith samples were fully equal, and I think rather superior, to the West Virginia, showing less abrasion and less granulation.

I hope you will continue your experiments in mixing varying quantities of the different clays until you have the strongest. Then you will have a superior paving brick.

Truly, yours,

R. S. Miller.

By the month of November, 1889, W. A. Doyle was using the Nigger Hill clay shales at Fort Smith in the manufacture of paving bricks. The business succeeded from the outset, and there was soon built up at that place a large and prosperous business in the manufacture of paving and building bricks from the shales.

Two analyses are here given of the Fort Smith clay shales, and for purposes of comparison analyses of the well-known Carboniferous shales of Akron. Ohio, and of Cheltenham, Mo., are added.

Analyses of clay shales.

[Specimens dried at 110°-115° C. Brackett & Smith, analysts.]

	Fort Smith.		Akron, Ohio.	Cheltenham, Mo.
	Harding & Boucher's quarry.	W. A. Doyle's paving-brick kiln.		
Silica (SiO_2)	57.10	58.43	60.05	54.92
Alumina (Al_2O_3)	23.74	22.50	20.00	22.71
Iron (Fe_2O_3)	8.18	8.36	6.82	9.81
Lime (CaO)	.53	.32	.52	.52
Magnesia (MgO)	1.04	1.14	.45	2.59
Potash (K_2O)	1.53	2.18	1.79	3.16
Soda (Na_2O)	.87	1.03	1.60	.62
Sulphur (S)	....	.16	1.95	....
Loss on ignition	7.21	6.87	6.96	5.88
	100.20	100.99	100.14	100.21
Sand	.12	25.72	29.12	2.04
Water at 110°-115° C	4.24	3.37	1.25	2.69

These Carboniferous shales outcrop at many places in the vicinity of Fort Smith and, indeed, in all parts of Sebastian County.[a] They are exposed at W. A. Doyle's paving-brick factory between Towson and Wheeler avenues, Fort Smith; at Harding & Boucher's quarry in the northeast corner of the SW. ¼ sec. 28, T. 8 N., R. 32 W.; and immediately across the Texas road from Harding & Boucher's quarry, on the railway track running through the SE. ¼ sec. 20 and the NE. ¼ SE. ¼ sec. 29 of the same township and range. They are also seen in a railway cut on the lands of the Oak Park Company in the SE. ¼ NE. ¼ sec. 35, T. 9 N., R. 32 W. At all these places the shales have disintegrated and formed a clay. A well on the Adams lot, in the NE. ¼ SW. ¼ sec. 15, T. 8 N., R. 32 W., shows a section of this clay 10 feet thick. At Harding & Boucher's quarry the clay formed from the disintegrated shale has a thickness of 6 feet, and in the railway cut through secs. 20 and 29 a thickness of 3 feet is visible. The analysis of the Harding & Boucher shales is given above.

There are exposures also in the banks of a small stream near Nowland's spring, in the NE. ¼ NE. ¼ sec. 34, T. 9 N., R. 32 W. In the SW. ¼ NE. ¼ sec. 9, T. 8 N., R. 31 W., near the center of the section, and in the SW. ¼ SW. ¼ sec. 7, T. 7 N., R. 31 W., and in a cutting on the Little Rock road in the SW. ¼ SE. ¼ sec. 15, T. 8 N., R. 32 W., similar shales are exposed. In these sections the shales are overlain by grayish-brown sandstone, and retain their shaly character in a greater or less degree according to the protection given to them by the overlying sandstone.

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[a] The notes on the occurrence of shales about Fort Smith are by William Kennedy.

In the section at Nowland's spring the bluff is protected by a covering of grayish-brown sandstone about 4 feet thick. The shales immediately under the sandstone are black, hard, and somewhat arenaceous. Thin beds of iron-stained quartz run throughout the upper 10 feet of the shales. Below, where they are exposed to the action of the waters of the stream, the shales form a soft, blue clay-like material. These blue shales are about 4 feet thick and overlie a series of soft black shales.

In the bluff overlooking Arkansas River in the SW. ¼ NE. ¼ sec. 19, T. 8 N., R. 31 W., near the center of the section, the covering is a heavy bed of brownish sandstone 7 feet thick. The shales beneath are light yellow for 5 feet immediately below the sandstone, and 3 feet of soft black shales are exposed below the yellow.

The quantity of talus along the bluff is so great that the shales are almost everywhere covered up. In the section shown at the end of the bluff in sec. 19 the sandstone projects about 7 feet beyond the underlying shales.

The following is a section at the end of the bluff in the SW. ¼ NW. ¼ sec. 19, T. 8 N., R. 31 W.:

Section in bluff of Arkansas River.

	Feet.
Brownish, heavily bedded sandstone	7
Soft, friable, yellowish shale, with whitish streaks in the upper division	5
Black shale somewhat harder than the yellow, and containing some red streaks	3
Talus covering black shales to the level of the river	150

A section in the SW. ¼ SW. ¼ sec. 7, T. 7 N., R. 31 W., gives the following:

Section in SW. ¼ SW. ¼ sec. 7, T. 7 N., R. 31 W.

	Feet.
Sandstones	7
Yellow shales, soft where exposed and forming dark yellow clay	4
Black shales	10
Sandstones	5
Blue shales	70
Black shales.	

The black shales lying at the base of the bluffs in sec. 19, T. 8 N., R. 31 W., and in secs. 24, 26, 34, 35, 27, and 28, T. 8 N., R. 32 W., on the north side of Massard Prairie, and in sec. 6, T. 7 N., R. 31 W., on the southeast side of the prairie, are the same beds, and they pass under Massard Prairie in an almost horizontal position. These shales are also seen at a few places where Massard Creek and one or two smaller streams have cut down through the overlying yellow prairie soil.

Wherever the shales are exposed they rapidly disintegrate and form a stiff clay, having approximately the colors of the shales from which the clay has been formed.

The following is a section at Doyle's paving-brick factory:

Section at Doyle's paving-brick factory.

	Feet.
Red sandy clay containing waterworn pebbles in considerable quantities	2
Blue and black shales interstratified and inclosing some thin beds of red arenaceous shale	25
Sandstone at the base.	

In this section the gravel and clay overlying the shales have partially obstructed the work of disintegration, so that the shales have not yet completely disintegrated. The softer blue shales have for the most part disappeared in the clay, but the harder black and red shales still remain in their shaly form, although somewhat soft and easily crushed.

Wherever the shales have been exposed by the removal of the overlying sandstones and gravel they readily lose their shaly character and assume the condition of a plastic clay, having the color and position in the series of the shales from which they are derived.

At Harding & Boucher's quarry, 1½ miles south of Fort Smith, in the northwest corner of the SW. ¼ sec. 28, T. 8 N., R. 32 W., the surface material consists of about 6 feet of disintegrated shales, which rests on the sandstone of the quarry. These shales have disintegrated and formed a gray mottled clay. In the lower part of the bed the disintegration is not always complete and fragments of shale are scattered through the clay. Analyses of these clays and shales are given below.

The shales exposed along the Missouri Pacific Railway track through the SE. ¼ sec. 20, T. 8 N., R. 32 W., are in the same disintegrated and clayey condition as those seen higher up the hill at Harding & Boucher's quarry.

Analyses of argillaceous shales from Fort Smith.

[Specimen dried at 110°-115° C. Brackett & Smith, analysts.]

	Nigger Hill.	Harding & Boucher's quarry.		
	1.	2.	3.	**4.**
Silica (SiO_2)	58.43	57.10	65.12	**42.12**
Alumina (Al_2O_3)	22.50	23.74	19.05	**18.84**
Ferric oxide (Fe_2O_3)	8.36	8.18	7.66	**26.35**
Lime (CaO)	.32	.53	.34	**.28**
Magnesia (MgO)	1.14	1.04	.31	**.74**
Potash (K_2O)	2.18	1.53	1.23	**1.10**
Soda (Na_2O)	1.03	.87	.85	**1.85**
Sulphur (S)	.16			
Loss on ignition (water)	6.87	7.21	6.12	**8.77**
	100.99	100.20	100.68	**100.05**
Sand in air-dry specimen	25.72	76.40	21.88	**None.**
Water at 110°-112° C	3.37	4.24	4.79	**3.19**

The Nigger Hill shale is from the paving-brick kiln of W. A. Doyle, on Towson road, Fort Smith; the other three are from Harding & Boucher's quarry in the northwest corner of the NW. ¼ sec. 28, T. 8 N., R. 32 W. Sample 2 is from the gray clay about 3 feet below the surface; sample 3 is from the yellow mottled with red; and sample 4 is from the undecomposed shale next to the sandstone beneath.

It is not possible to specify all the places at which clay shales available for the manufacture of bricks, sewer pipe, and similar products may be found in Sebastian County. They are associated with the coal at many places in the coal mines. Many of the clays that lie immediately beneath the coal are available as fire clays.

A specimen of gray clay from KcKenna's quarry, near Hackett City, was sent in by Mr. Ed. McKenna. The analysis is given below.

Analysis of gray clay from McKenna's quarry, at Hackett City.

[Material dried at 110°-115° C. R. N. Brackett, analyst.]

Silica (SiO_2)	54.13
Alumina (Al_2O_3)	30.69
Ferric oxide (Fe_2O_3)	3.15
Manganese oxide (MnO)	Trace.
Lime (CaO)	.63
Magnesia (MgO)	.94
Potash (K_2O)	.49
Soda (Na_2O)	2.01
Loss on ignition	8.54
	100.58
Water at 110°-115° C	4.82

At the Hartshorn coal mine, 4 miles south of Fort Smith, is a bed of dark-gray shale 4 feet thick., A sample was sent to the Survey by Mr. W. A. Doyle, of Fort Smith, and analyzed, with the results given below. The relation of this shale to the coal at the mine is not stated.

Analysis of shale from the Hartshorn coal mine.

[Material dried at 110°-115° C. R. N. Brackett, analyst.]

Silica (SiO_2)	70.83
Alumina (Al_2O_3)	17.49
Ferric oxide (Fe_2O_3)	3.64
Magnesia (MgO)	.91
Potash (K_2O)	.25
Soda (Na_2O)	1.72
Loss on ignition	4.95
	99.79
Water at 110°-151° C	.76

The region about Mansfield may be taken as a type of the topography and geology of most of the country south of Fort Smith. The accompanying section (fig. 17), by Professor Purdue, shows the general character of the geology and the relation to each other of the shales and sandstones of the region. There are long parallel ridges of sandstone with shale valleys between. The shales are at some places so interbedded with sandstones that they are hardly available for manufacturing purposes on a large scale, but for the most part they form beds of enormous thickness and of a composition suitable for making paving bricks, sewer pipe, and fire-clay goods. Just north of Mansfield the heavily shaded area in the section represents the clay shales used by the Choctaw Pressed Brick and Terra Cotta Company.

One-half mile south of the town an almost unbroken ridge, known as Coops Ridge, incloses a small circular valley. The ridge is made up of sandstones that dip southward on the south side and northward on the north side; in other words, Coops Ridge surrounds a small anticlinal valley, called Coops Prairie. Inside of this valley are thick beds of clay shales that are probably available for the manufacture of various kinds of clay goods. The valley between Coops Ridge and the town of Mansfield is more than a quarter of a mile wide and is cut in shales that extend westward to Cherokee Prairie and then swing back eastward around the south side of Coops Ridge and form the broad, open valley that lies about the village of Fuller, in Scott County, and extends a mile east of it, and then swing westward again and around to Mansfield. North of Black Jack Ridge is another shale valley not more than a quarter of a mile wide that extends from James Fork, 4½ miles west of Mansfield, northeastward past Mansfield 4 miles, and swings westward past the town of Dayton, which stands in the shale valley. Another shale valley parallel in the main with the last one mentioned begins a mile south of Liverpool post-office and runs northeastward parallel to and just south of Nigger Ridge, crossing Cherokee Creek a mile south of the town of Huntington, and about 2½ miles farther east it swings northward and then westward about 4 miles, when it turns due northward and extends for 5 miles or more along the east base of Devils Backbone Ridge. This same bed of shale can be traced for many miles along the base of this ridge past Burnsville post-office into the eastern edge of Sebastian County.

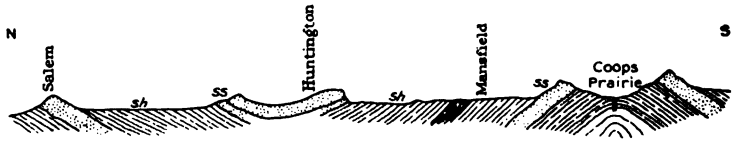

FIG. 17.—North-south section showing structure and relative positions of the shales and sandstones from Coops Ridge to Salem. *sh*, Shale; *ss*, sandstone.

This description is doubtless sufficient to show that the clay shales of Sebastian County are widespread over the entire county, and that the beds are of great thickness. The value or availability of each bed has not been determined, but such tests can be made practically whenever it becomes necessary to consider the location of a manufacturing plant, and a brief examination of the geology should show the distribution of the materials.

POTTERY CLAYS.

It has already been pointed out that the shales of this region break up or decompose under the influence of the weather, forming plastic clays. Such clays are available for the manufacture of paving bricks and sewer pipe, or for pottery. Clays thus formed are about the only ones used for the manufacture of pottery in the upland regions of Sebastian County.

The only pottery clay that was used in Sebastian County in 1889 came from the S. ½ SE. ¼ sec. 27, T. 7 N., R. 30 W. An examination of the geologic structure of the region in which it is found affords evidence of its origin and suggests where other and similar clays may be found in this county.

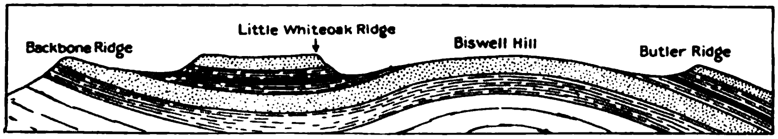

FIG. 18.—North-south section through Biswell Hill.

The place at which this clay occurs is at the north base of Little White Oak Ridge. This ridge runs southwestward toward Greenwood and northeastward past Auburn post-office, where it curves westward, merges into Butlers Ridge, runs northwestward and ends at Butlers Knob, in sec. 10 of this same township and range. To the west of Biswell Hill it appears again, striking away to the west and southwest, where it is known as Tennessee Ridge. The rocks of this line of ridges dip away from Biswell Hill on all sides, and a north-south section through Comby's clay pits would expose the rocks as they are shown in the section below.

A section across Little White Oak Mountain, Biswell Hill, and Tennessee Ridge would display practically the same structure as that shown above. This structure explains the origin of the Comby clays and suggests at the same time that similar clays may extend along the northwest side of Little White Oak Ridge, the southwest side of Butlers Ridge, and the south side of Tennessee Ridge.

The example cited above is given for the purpose of illustrating the general features of the geologic structure of Sebastian County and to show the origin of the residuary pottery clays rather than to explain the presence of clay at a single locality. Throughout the entire county the rocks are thrown into folds and eroded, and wherever the argillaceous shales are exposed to decomposing agencies they have been changed into plastic clays.

In searching for the clays, or the clay shales from which they are derived, one must keep in mind the structural features of the region and the agencies by which the clays are produced and modified. It should not be forgotten, however, that sedimentary rocks frequently change in character in passing along the outcrops, so that what is a sandstone at one place may be an arenaceous shale at another and an argillaceous shale at a third locality.

The upland clays of Sebastian County are confined to the region of Paleozoic rocks. These clays, however, are not all produced by decomposition directly from the argillaceous shales. Some of them have been washed into the valleys and, mingled with the residual rocks of the region, have formed "buckshot clays" by precipitation within them of the iron carried in solution by percolating waters. The method by which these clays are formed is described in Chapter II of this report. These "buckshot clays" are not available for the manufacture of pottery, but they are used more or less for making bricks.

COMBY'S CLAYS.

The clay formerly used at Comby's pottery is a light-yellowish surface clay, found in a low-lying piece of ground in the S. ½ SE. ¼ sec. 27, T. 7 N., R. 30 W., where it has a depth of about 2½ feet. The mode of origin of this clay has already been described.

Analysis of Comby's pottery clay.

[Brackett & Smith, analysts.]

Silica (SiO_2)	81.61
Alumina (Al_2O_3)	10.52
Iron (ferric) oxide (Fe_2O_3)	2.70
Lime (CaO)	.32
Magnesia (MgO)	.40
Potash (K_2O)	.66
Soda (Na_2O)	.57
Manganese (MnO)	Trace.
Water (H_2O)	3.95
	100.73
Water at 110°-115° C	3.86
Fine sand	18.43

The ware from this clay is of poor quality and consists chiefly of such articles as are in local demand, such as churns, jugs, crocks, and jars. No other kinds of ware have been manufactured. It can not be said that this clay has been so tested as to establish or disprove its availability for the manufacture of pottery.

Close to the kiln and on the same quarter section there is a small deposit of stiff light-blue clay which has been turned for pottery, but without success. When this blue clay was used alone the ware made from it cracked in drying. A mixture of this and a pale-blue, almost white, sandy clay from the NE. ¼ NE. ¼ sec. 7, T. 6 N., R. 30 W., has also been tried with some success. The results, however, were not altogether satisfactory and the work was abandoned.

The pale-blue sandy clay from sec. 7, T. 6 N., R. 30 W., outcrops at several places along the side of a small hill and in the bottom and banks of a small stream that crosses the wagon road leading from Greenwood to Charleston. Mr. Comby tried this clay alone for the manufacture of pottery, but with the appliances at command he did not succeed. When mixed with the surface clay from the SE. ¼ SE. ¼ sec. 27, T. 7 N., R. 30 W., the results were fairly successful.

GLAZING MATERIAL.

Mr. Comby tried a black silt found on the bottom lands at the mouth of Vache Grasse Creek for glazing purposes. It is said to have served the purpose of a slip, but not much reliance can be placed upon the experiment. Analyses of this river deposit and of the Albany slip have been made by the Arkansas Geological Survey.

Analysis of Vache Grasse and Albany slip.

[Brackett & Smith, analysts.]

	Vache Grasse slip.	Albany slip.
Silica (SiO_2)	70.95	58.05
Alumina (Al_2O_3)	12.24	14.86
Iron (ferric) oxide (Fe_2O_3)	4.73	6.76
Lime (CaO)	1.90	6.61
Magnesia (MgO)	.97	3.08
Potash (K_2O)	1.14	1.18
Soda (Na_2O)	.66	.80
Water (H_2O)	7.01	7.41
	99.60	98.75

PRAIRIE CLAYS.

Over the whole of the upland portion of Sebastian County the soils are derived by decomposition from the rocks. The materials are shifted somewhat—washed down from the slopes and spread over the valleys—and are afterward more or less leached and altered by secular weathering. This process produces what are popularly known as "buckshot clays" of the prairies and slashes. These clays are not specifically mentioned as characteristic of this county, but as they are derived chiefly from the shales they are mentioned under this general head.

The whole of sec. 3, the greater part of sec. 2, the SE. ¼ sec. 4, the NE. ¼ NE. ¼ sec. 10, and the NW. ¼ sec. 11, T. 8 N., R. 32 W., are covered with a yellowish buckshot clay, or prairie soil, containing considerable quantities of iron nodules about the size of a pea. The section in the banks of a small stream running through sec. 3 shows a thickness of about 3 feet of this clay.

In sec. 4 of the same township and range a similar yellow loam overlies a deposit of dark-red clay. In the W. ½ NW. ¼ sec. 35, T. 9 N., R. 32 W., a band of chocolate clay about 4 feet thick lies between the two yellow divisions of the exposed clays. The chocolate clay forms the surface for some distance and then passes under a heavy bed of yellow clay.

The surface soil of Massard Prairie is a yellow clay or prairie soil, having a general thickness of about 4 feet. This clay rests on the dark-blue or black shale which is seen at the base of the different sections exposed in the bluffs on the north and south sides of the prairie. A section from the bank of a small creek in the SW. ¼ SE. ¼ sec. 1, T. 7 N., R. 32 W., may be taken as a representative section of this prairie.

Section in SW. ¼ SE. ¼ sec. 1, T. 7 N., R. 32 W.

Thin covering of humus at surface.	Feet.
Yellow (almost orange-colored) clay containing nodules of iron in its lower division	4
Black or dark-blue shales, broken into kidney-shaped pieces at base.	

Where the soil has been washed off the surface the ground is covered with the nodules of iron in the shape of gravel.

In the NE. ¼ SE. ¼ sec. 19, T. 8 N., R. 31 W., the surface soil is red clay, and in the S. ½ sec. 29, on the south side of Massard Creek, a yellow clay overlies the coal in some of the openings.

In the NW. ¼ SW. ¼ sec. 29, T. 8 N., R. 31 W., near Massard postoffice, a dark-red clay covers the small hill lying to the southeast of the prairie.

Nothing has ever been done to demonstrate the usefulness of these clays for any purpose. There is little doubt, however, that many of them might be profitably used for the manufacture of ordinary building bricks, and for this purpose the clays found on Massard Prairie and on the prairie-like district of secs. 2, 3, 4, and 10, T. 8 N., R. 32 W., will probably be much better adapted for making a hard, solid brick than the red earth found close to Fort Smith and used at present. It may be safely said that these clays will, with proper treatment, make as good and as strong a brick as can be found anywhere else throughout the valley of Arkansas River.

TERRACE CLAYS.

Over the lowlands near Arkansas River, in some places extending back inland for several miles, generally in the form of terraces, there is a system of unconsolidated deposits which are probably of Pleistocene age. The material forming these terraces are yellowish, reddish, and lead-colored loams, clays, sands, and gravels. They lie in horizontal beds, but have been cut and more or less mutilated by erosion over the whole surface and by streams that cross them to enter Arkansas River. These Pleistocene deposits cover most of the plain on which the city of Fort Smith stands, and the peninsula extending northeastward toward Van Buren, where fragments of them occur here and there along the river east of Fort Smith. The clays of this series are exposed in what may be regarded as a typical section along the railway near the Ketcham iron works and at other points south of the city. The uppermost bed is a yellowish clay, in some places more or less mottled and in others containing small, friable nodules of iron. Although its characteristic color is yellow, this bed is in some places ashen gray and in others bright red.

In the typical section just mentioned the next bed below the yellow clay loam is a dark-red clay which contains a good deal of sand and which is about 10 feet thick. Below it is a bed about 1 foot thick of deep-red to chocolate-colored clay, and below lies a bed of fine sand. The bottom of the sand is not exposed. The thickness and quality of these beds varies greatly; the yellow loam is entirely wanting in many places, having been removed by erosion, while the red clay may contain occasional beds of sand.

It can not be positively stated that pottery clays do or do not exist in these Pleistocene river terraces, but the nature of the beds seen is favorable to the occurrence in them of pockets of pottery clays. In these terraces or second bottoms extensive deposits of brick earth are found, both in Sebastian and in adjoining counties.

RECENT ALLUVIUM.

The Pleistocene terraces referred to above are distinct from the river-bottom silts. The latter stand at a lower level and are usually less brilliantly colored. No pottery clays are now known in the bottom, but it is possible that they may occur there. As a rule the alluvial deposits are silts and sands rather than clays, and such pottery clays as they contain will probably be found only in pockets.

CLAY INDUSTRY.

UTILIZATION OF THE CLAY SHALES.[a]

Although the clay shales of Fort Smith and of Sebastian County are suitable for the manufacture of sewer pipe, fire bricks, and pottery, nothing has been done thus far to utilize these shales for making such articles. The abundance of excellent raw materials, the proximity of the deposits to the coal fields, and the possibility of building up a larger trade in clay products in the South and Southwest ought to lead to the early development of such industries at some point in Sebastian County.

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[a] The notes on the brick industries of Fort Smith are chiefly by William Kennedy.

Chemical analyses of the argillaceous shales show them to be clays so far as their chemical composition is concerned. They have been changed, however, by pressure and time in physical appearance and character. The chemical composition of these clay shales of Sebastian and adjoining counties suggests the possibility of using them, when ground and washed, for the manufacture of the common grades of pottery. The clay shales have the average composition shown in the table below. For the purpose of comparing this with the pottery clays of the Tertiary region of the State (Benton, Perla switch, etc.) the average composition of the latter is given in an adjoining column.

Analyses of clay shales and of Tertiary pottery clays.

	Clay shales.	Tertiary pottery clays.
Silica (SiO_2)	58.91	68.20
Alumina (Al_2O_3)	22.21	21.79
Iron (ferric) oxide (Fe_2O_3)	7.64	1.77
Lime (CaO)	.53	.20
Magnesia (MgO)	1.37	....
Potash (K_2O)	2.15	1.12
Soda (Na_2O)	.93	1.16
Water (H_2O)	6.64	6.44

The clay shales contain a somewhat higher percentage of the bases (iron, lime, magnesia, potash, and soda), elements which increase the fusibility of the material, and a lower percentage of silica. The higher percentage of iron in the clay shales would give the pottery made from it a dark color like that of sewer pipe, but this objection would not apply seriously to jugs and many other articles. The upper weathered portions of the beds can be ground more readily, while the already decomposed and plastic clays that usually cover the exposed surfaces of these shale beds may advantageously be mixed with the crude material.

BRICK PLANTS.

Paving bricks.—It is only since 1889 that the manufacture of paving brick has been carried on at Fort Smith. Mr. W. A. Doyle had the first contract for the paving of Garrison avenue, and 3,000,000 bricks were required for this purpose. The bricks were made from the disintegrated shales found on Towson road between Towson and Wheeler avenues. The shales were ground before pugging. For this purpose a Penfield crusher was used. The clay was then pugged in a No. 10 D pug mill, and the bricks were made in a No. 20 B Penfield machine having a daily capacity of 50,000 bricks. The machinery was driven by steam power. The bricks were end cut and dried in a steam heated drying shed and burned in the ordinary open kiln. The fuel used was a mixture of coal and wood.

In drying these bricks part with their water very slowly, and it usually requires about six days to dry them sufficiently to be put in the kiln. The time allowed for burning is from ten to twelve days. When burned hard the outside bricks are dark brown and the inside bricks dark blue. In the kiln used at Fort Smith the outside bricks were bright red.

Clays formed by the disintegration of these shales shrink considerably in drying and burning. The bricks made at Fort Smith shrink about 1½ inches in the length of the brick (9½ inches), and the average settling of a kiln 36 bricks high is about 2 feet.

In setting the kiln it is necessary to set the rows close to one another in order to provide for the widening of the spaces between the rows of bricks due to the shrinkage.

There are at present three brick plants in Sebastian County. Two of these are in Fort Smith and the other at Mansfield.

The Choctaw Brick and Gas Company.—A plant was established in 1901 at Mansfield, in the southeastern part of the county, by the Choctaw Brick and Gas Company. Common building bricks are made from Carboniferous shale. The shale is pugged and molded in the Berg machine. The bricks are dried in sheds and nine to ten days are required to dry them sufficiently to place in the kiln. They are burned in up-draft and down-draft kilns, which hold from 50,000 to 250,000 bricks each. Five kilns are in use. The kilns are arranged to use coal and natural gas for burning, and about one-half ton of coal is consumed for each 1,000 bricks. The length of time for burning a kiln is about fifteen days. The shrinkage of the clay is about one-sixteenth. The output of the plant is 20,000 a day.

Plants at Fort Smith.—The two plants located at Fort Smith are the Fort Smith Paving Brick and Fire Clay Company, Louis Ismay & Brother, lessees, and a plant operated by John D. Carbaugh. Detailed information concerning these plants was not obtained.

The material used in the manufacture of the ordinary red building brick at Fort Smith occupies a district west of the city that includes the greater portions of secs. 9 and 16, the whole of fractional secs. 8 and 17, and the northwestern portion of sec. 20, as well as the SW. ¼ sec. 4, all in T. 8 N., R. 32 W. The SW. ¼ SE. ¼ sec. 34, T. 9 N., R. 32 W., also contains a red earthy clay from which bricks have been manufactured.

This brick earth is a stiff clay which is in places mixed with so much sand that the beds have the appearance of homogeneous deposits of sandy clay. It is, however, very irregular in its texture, varying within short distances from stiff clay to loose sand. Both sand and clay are of a red color, dark red when wet and pale yellowish brown when dry and exposed for any great length of time. At Messrs. Bocquin & Reutzel's old location on the strip of land lying between Towson road and Wheeler avenue, Fort Smith, on the west side of the SE. ¼ sec. 17, T. 8 N., R. 32 W., the clay has a pale-yellowish, almost gray, color.

The average thickness of this mixed clay and sand varies considerably, but averages about 6 feet. A section taken close to the line between Oklahoma and Arkansas, near the bank of Poteau River, gives the following section:

Section near Poteau River.

	Feet.
Reddish-gray sand	2
Red clay	3–6
Red sand	6–8

The bottom of the red sand is not reached in this exposure.

In the district between Arkansas River and Poteau River, along Fourth street in Fort Smith, the red sand and clay have been penetrated to a depth of 12 feet. The sand and clay seem to be overlain by a course white river sand. In this district the clay also becomes much more sandy.

Bricks made from the brownish-yellow sandy material are soft and will not bear much rough handling. They are readily injured by rain and ought to be dried under cover. In the kiln they will not stand a heat sufficiently high to make hard bricks without fusing. It is no uncommon thing for the arches to fall in, and when the kiln is opened the bricks forming the broken arches are found to be a fused mass of half-burned clay and dark-greenish slag. The result of this tendency to fuse is that the bricks must be burned soft and will not bear rough handling or resist the crushing strain imposed on bricks used in the erection of heavy structures. The loss through breakage in handling is also considerable, amounting in most yards to 15 or 20 per cent. When burned these bricks have a bright-red color, and when re-pressed for front or face bricks they are darker and have smooth faces and square corners. The color of bricks of this class is uniform and good.

The following analyses of this clay dried at 110°–115° C. show its composition:

Analyses of clay from Fort Smith.

[Brackett & Smith, analysts.]

	1.	2.	3.	4.	5.
Silica (SiO_2)	83.83	84.00	74.79	76.26	76.20
Alumina (Al_2O_3)	9.32	8.33	12.86	11.74	12.41
Ferric oxide (Fe_2O_3)	2.64	2.73	4.90	4.54	4.36
Lime (CaO)	.34	.27	.38	.39	.49
Magnesia (MgO)	.45	.35	.90	.79	.54
Potash (K_2O)	1.27	.83	1.73	1.28	1.21
Soda (Na_2O)	.85	.82	1.49	.98	.84
Loss on ignition (water)	2.40	2.81	2.91	3.82	3.75
	101.10	100.14	99.96	99.80	99.80
Fine sand	38.23	37.57	29.77	47.79	11.89
Water lost at 110°–115° C	2.21	2.45	2.76	3.71	4.06

No. 1 is the lighter colored clay from the bank opposite Ketchum Iron Company's shop; No. 2 is the yellow clay overlying No. 3 at the Ketchum Iron Company's shop; No. 3 is the lower reddish clay at Ketchum Iron Company's shop (underlying No. 2); No. 4 is the red sandy clay from Messrs. Pendell & Morrison's old brickyard; No. 5 is an ashen-gray clay from the south end of the Fort Smith and Dardanelle Railway.

POTTERIES.

Comby's pottery.[a]—This pottery was situated in the SE. ¼ SW. ¼ sec. 28, T. 7 N., R. 30 W. The kiln was a small one, built of stone cemented with clay, and was half underground—the kind of kiln sometimes called "groundhog." It was not adapted to salt glazing, and the Albany slip or black glaze was used. Sometimes a little salt was thrown into the kiln, but it affected only the ware at the front of the kiln next the fire, and that not always beneficially. There was nothing to protect the ware from the ashes of the fire, and every time a fresh supply of fuel was added or the fire touched the lighter ashes were sent in a shower among the hot ware, to settle down on the articles in the process of burning to become fixed to them by the glaze. The result of this is that the ware, especially that portion of it next the fire, presents anything but a pleasing appearance. With such a method of firing, a good class of pottery could not be made even with the best of pottery clays. The poor results obtained at this pottery must be attributed for the most part to the methods employed in burning the ware, though it is in part evidently due to poor raw material or to the improper treatment of the clay.

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[a] The notes and statistics of Comby's pottery were collected by Mr. Kennedy. The plant has gone out of business.

Caldwell's pottery.—A small deposit of bluish-white sandy clay mottled with red is found on the north side of a small creek in the SE. ¼ SE. ¼ sec. 10, T. 6 N., R. 31 W. This was at one time used to supply a pottery at Greenwood owned by Mr. Caldwell, but clay from this place has not been used for a number of years.

UNION COUNTY.

GENERAL GEOLOGY.

The strata underlying Union County consist almost exclusively of soft uncompacted clays, sand, brown coals (or lignites), and gravels of Tertiary age. The horizontality of these beds makes the geology comparatively simple. The clays are of various colors, exhibiting all the shades of brown, yellow, red, and gray. The highest beds of the county are those that cap the divide on which Eldorado stands. These beds are sandy clays and clayey sands, covered here and there by gravels of novaculite and quartz. From this elevated divide the surface of the county slopes away on all sides, the streams cutting deeper and deeper into the soft horizontal rocks. Along their banks, where bold headlands are left in the process of stream erosion, the stratification of the Tertiary beds is occasionally well exhibited. The best exposures, however, are in the river bluffs along the Ouachita at places where the river hugs the foot of the bluff closely, as at Camden, Newport Landing, Millers Bluff, Wilmington Landing, and New London. At Wilmington Landing the section exposed is typical of the geology of the entire highland region of the county.

The beds there exposed continue with some variation toward the west and underlie a large part of Union County, and in all probability underlie Columbia County also. In the deeper channels of the larger streams the beds of soft rocks are penetrated to greater depths and the entire section given on page 220 is exposed here and there, though generally only in fragments.

Where erosion has not been so powerful and so concentrated as in the immediate neighborhood of Ouachita River the stream channels are broader and their sides less abrupt, so that the clays and other beds have thinner coverings along the side valleys that extend inland from the river.

The lignites of Union County are of the same kind as those of Ouachita County. Aside from any direct use to which the coal may be applied, it serves as a guide in searching for clays, for the clays are at many places associated with the lignite, either overlying or underlying it. Persons acquainted with the geology of this county report that at many places a bed of clay 15 feet thick overlies the lignite. The clay beds at Wilmington Landing and at

New London Landing, on Ouachita River, overlie the lignite exposed in the river bluff at those places. This clay, however, is not everywhere valuable.

CLAY DEPOSITS.

In the neighborhood of Beach Creek, where it is crossed by the Mount Holly-Lisbon road, many small fragments of fine potter's clay are scattered through the sandy clays. These fragments are of no value in themselves, but their presence suggests the probability that they were derived from deposits of fine potter's clays in this neighborhood. Similar evidence of the presence of good clays are common at many points in both Union and Columbia counties. About Lisbon such clays are exposed in deep gullies, especially on the west side of the town, near Camp Creek, and also on Holmes Creek.

About 2 miles west of Lisbon, on the Lisbon-Mount Holly road, just west of the Rose farm, on the brow of a westward-sloping hill, 3 or 4 feet of dove-colored potter's clay is exposed by the roadside. The total depth of the bed, however, is not visible. In places this bed contains very thin laminæ of fine sand, which may prove injurious.

East of Lisbon the clays and sands are thinly laminated and interstratified, so that they are not available for the manufacture of pottery or fire-clay products.

Four miles west of Eldorado, on the road to Lisbon, there are some rather promising looking exposures, but so far as examined they contain too many streaks of sand to be useful. Further search in the vicinity is likely to discover good beds.

One and one-fifth miles west of Eldorado, on the Lisbon road, on the side of a hill facing westward, the following section is exposed:

Section near Eldorado.

	Ft.	in.
Yellow soil and clay at surface.		
Good pink clay with fossil leaves	1	
Gray, rather sandy potter's clay	4	
Pink sandy clay		8
Dull pink sands exposed	2	

The clays exposed by the Eldorado-Lisbon road, about 400 feet west of the first milepost west of Eldorado, are all or nearly all too sandy to be available for the manufacture of pottery.

Three miles east of Eldorado the road to Wilmington Landing passes over a bed of pink potter's clay containing abundant leaf impressions. On the south side of the road the bed is about 4 feet thick, but it is not exposed on the north side of the road.

About 1¼ miles southwest of Wilmington Landing, on the edge of the flat woods, some fair pottery clays are exposed by the roadside, but their thickness is not evident.

There are said to be some very fine clays on Lapile Creek in T. 18 S., R. 13 W., probably in sec. 9 or 10.

At Wilmington Landing the Tertiary beds are well exposed in the river bluff and in the gullies that furrow its sides.

Section of river bluff at Wilmington Landing.

	Feet.
1. Sand on hilltop	2
2. Sandy clay	5
3. Light-gray clay	2
4. Pinkish clay	3
5. White sand with some clay	9
6. Fat buff clay with some sandy patches and lignite	16
7. Tough, somewhat sandy, light-colored clay	7
8. Fat gray clay	6.
9. White sand	3
10. Outcrop of brown coal	3
11. Fat dove-colored clay	3
12. Sands with clay laminæ	5
13. Pink sandy clays with fossil leaves	6
14. Sandy clays and sands	10
15. Concealed to the level of Ouachita River	10
	90

The hills one-eighth of a mile south of Wilmington Landing continue upward the section given above. It is approximately as follows:

Section south of Wilmington Landing.

	Feet.
Clays and clayey sands at the surface.	
Lead-colored and pink pottery clays	12
Sands	6
Chocolate-colored sandy pottery clays	4
Lignite	3

The horizontality of the Tertiary beds of the region and the outcrops of lignite along the bluffs and foothills of the region point to a wide distribution in Union County of the clay beds exposed in the section given above.

A specimen of the clay bed No. 6 of the Wilmington Landing section was analyzed.

Analysis of buff clay from Wilmington Landing.

[Specimen dried at 135° C. W. A. Noyes, analyst.]

Silica (SiO_2)	64.97
Titanic oxide (TiO_2)	.40
Alumina (Al_2O_3)	18.87
Iron oxide (Fe_2O_3)	5.26
Lime (CaO)	.63
Magnesia (MgO)	1.00
Potash (K_2O)	1.43
Soda (Na_2O)	.30
Water (H_2O)	7.43
	100.29

The large percentage of iron in this sample is probably due to infiltrations, the specimen having come from near the surface. Clay under cover will probably be found freer from this impurity and available for pottery ware and for other purposes for which basic clays may be used.

CLAY INDUSTRY.

But one plant in Union County is engaged in the manufacture of clay products—the Felsenthal Brick Company, at Felsenthal. The plant was established in 1904 for the manufacture of stiff-mud building bricks. They are made from the common surface red clay. The clay is tempered and molded in a Sword machine run by steam. The bricks are dried in a shed and burned in an up-draft kiln. Four kilns are in use, each having a capacity of 200,000 bricks. It requires six to ten days for the bricks to dry sufficiently to set in the kiln, and from six to eight days for burning. Wood is used as fuel. The plant has an output of 30,000 bricks a day.

The potter's clays of Union County are not utilized. There was at one time a pottery on what was formerly known as the "poorhouse farm," sec. 34, T. 17 S., R. 15 W., a little more than a mile southeast of Eldorado. It was operated by Mr. Leonard as late as 1860, and was probably closed by the civil war. The pottery made is said to have been of ordinary grade. The clays used are reported to have come from the "slashes" and not from a bed in place in the hills.

There was another pottery in Union County before the civil war, about 4 miles below Wilmington Landing. The ware burned light gray and was of good texture. The clay came from the stratified beds in a bank. This pottery is no longer in existence.

There is no lack of clays in Union County for the manufacture of good pottery and of fire-clay goods. It is possible that valuable clays may cover as much as half of the total area of the county. Though analyses have not been made of all the varieties of clay found in Union County it may safely be assumed that the clays are similar to those of Ouachita County, many of which have been analyzed. Until recently there was a lack of prompt transportation, for there was no railroad in the county, but the railroad from Camden to Eldorado and other railroads lately completed now afford cheap transportation for any clay goods that may be manufactured from the fine clays along Ouachita River.

WHITE COUNTY.

GENERAL GEOLOGY.

PRINCIPAL FEATURES.

The part of White County lying west of the St. Louis, Iron Mountain and Southern Railway is made up chiefly of sandstones, grits, and shales belonging to the lower Carboniferous or Mississippian series. In the extreme northwest corner of the county, about Rosebud and Romance, these beds are very nearly horizontal, and the streams have cut through the steep-sided and rather narrow valleys. Here the harder beds of sandstone form broad, flat areas with rather abrupt edges. In the southwestern part of the county and in the region between Searcy and Griffin Springs the same series of beds has been greatly folded, so that the beds dip toward the south on one side of the folds and toward the north on the other. In the folded area the alteration of hard beds of sandstone with soft beds of shale has given rise to alternate valleys and ridges, for the resisting sandstones withstand weathering and form the ridges, while the beds of shale break down into soft, easily washed clays, which are carried away, forming the valleys. The relations of these interfolded shales and sandstones are of great importance to anyone studying the distribution of the clays and clay shales, for it often makes it possible to trace the same bed for many miles across the county.

In the region just north of the town of El Paso the parallelism of the sandstone ridges and shale valleys is a striking feature of the topography. These ridges and valleys begin a few miles west of Buble and some of them swing northward around Antioch Mountain and then pass nearly due west to the vicinity of Caldron Creek, just north of Conway, in Faulkner County. Similar ridges beginning just north of the town of Austin can be traced nearly to Palarm Bayou, south of Preston, in Faulkner County. The valleys parallel with these sandstone ridges are all cut in shales, and it is to these shales that attention is directed. Some of these shales are too sandy to be utilized, but others are well adapted to the manufacture of paving brick and sewer pipe, and some of them are good fire clays.

The geology of Round Mountain, in the extreme southwest corner of White County, has been examined for the purpose of determining the character of these shales. The geology of that particular hill is therefore given here in detail.

ROUND MOUNTAIN.

A great syncline or troughlike valley known as Cypress Valley extends from the vicinity of Beebe to Arkansas River west of Conway. In the middle of this synclinal, in White County, in secs. 5, 6, 7, and 8, T. 5 N., R. 10 W., stands an isolated table-topped hill known as

Round Mountain. This hill rises about 200 feet above the surrounding valley, and has in general outline, as seen on a map, the form of a dumb-bell.

The sections given in fig. 19, taken at the opposite ends of the mountain, and the north-south profile section in fig. 20 show that while Round Mountain contains some coal and is capped by sandstone it is made up for the most part of argillaceous shales.

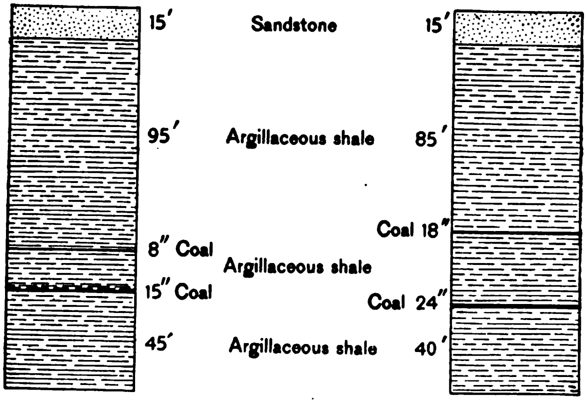

FIG. 19.—Sections of beds at Round Mountain.

The coal bed in section 2, fig. 19, was reported to have a thickness of 42 inches until 1892, when Mr. Charles Kantorowicz, of Little Rock, the owner of the Round Mountain property, engaged Capt. R. N. Scruggs to open the drift and definitely determine its thickness. The thickness here reported is that given by Captain Scruggs.

Where the shales near the base of the mountain have been covered by the débris from its sides they are already deeply disintegrated. The great body of the hill, however, is of compact shale, weathering in the usual way on exposure and breaking up in small prisms and cuboidal fragments. Much of this shale, possibly all of it, is available for the manufacture of fire bricks, sewer pipes, furnace linings, etc., and for road-paving bricks. The following are analyses of two samples of shales from Round Mountain and of two other similar shales from Missouri and Ohio, the analyses of the latter being introduced here for comparison:

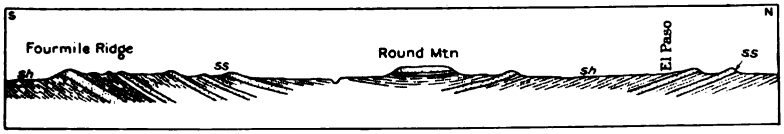

FIG. 20.—Theoretic north-south section through Round Mountain. *sh*, Shale; *ss* sandstone.

Analyses of shales from Round Mountain, Ark., Cheltenham, Mo., and Akron, Ohio.

	Round Mountain.		Missouri.	Ohio.
	1.	2.	3.	4.
Silica (SiO_2)	64.04	57.12	56.86	60.05
Alumina (Al_2O_3)	21.55	24.32	28.07	20.00
Ferric oxide (Fe_2O_3)	5.01	8.21	5.03	6.82
Lime (CaO)	.59	.72	.27	.52
Magnesia (MgO)	.96	1.74	.32	.45
Potash (K_2O)	1.56	2.07	.11	1.79
Soda (Na_2O)	.80	.53	.96	1.60
Loss on ignition	5.94	7.58	10.88	6.96
Sulphur (S)	.14	.22	....	1.95
	100.59	102.51	102.50	100.14
Water loss at 110°-115° C	1.36	1.75	3.84	1.25

1. From the bed of shale lying between the two coal beds exposed at west end of mountain. J. P. Smith, analyst.
2. From above uppermost bed of shale in the section. J. P. Smith, analyst.
3. From shale banks at Cheltenham, Mo. This is the material of which the Laclede Company manufactures its fire-clay goods. Brackett & Smith, analysts.
4. From Akron, Ohio; material used in the manufacture of sewer pipes, etc. Brackett & Smith, analysts.

A comparison of these analyses shows that the clay shales of Round Mountain are well adapted to the manufacture of fire bricks, sewer pipes, and such goods as are made of the similar clay shales at Cheltenham, Mo., and Akron, Ohio, as well as of paving bricks for roadways.

The coal in Round Mountain may perhaps be utilized in connection with the shales. At the west end of the mountain Mr. W. S. Brewer has opened a drift on a bed of coal which he reports to be 14 inches in thickness.

Immediately above the coal lies 20 to 24 inches of coal dirt or crushed bony coal. During and since the civil war Mr. Charles Kantorowicz's coal mine at the east end of the mountain was operated, but the drift has been abandoned since the spring of 1877, and the opening has been closed by the caving in of its sides. It was therefore impossible to examine the thickness of the coal bed at this place at the time it was visited. In 1892 Mr. Kantorowicz employed Capt. R. N. Scruggs to open the drift, and it was found that the coal was 24 inches thick 41 feet from the outcrop. Unfortunately it has not been possible to obtain a sample from the Kantorowicz mine, but analysis was made of a sample from Mr. Brewer's pit, which probably fairly represents the quality of coal of this lower and more important bed. The specimen was taken from the 8-inch bed high on the side of the mountain, and the coal is of good quality, as may be seen from the following analysis:

Analysis of Round Mountain coal.

[R. N. Brackett, analyst.]

Water	1.224
Volatile matter	10.298
Fixed carbon	78.119
Sulphur	3.149
Ash	7.210

Round Mountain is easy of access either from Beebe or Conway, Cypress Valley being well disposed for the location of a railway line.

Cypress Valley, especially the country about Round Mountain, abounds in good brick clays, while the region is well timbered.

There are other shale hills in the Cypress Valley syncline, the largest of which is about 7 miles east of Conway, Faulkner County, in secs. 11 and 14, T. 5 N., R. 12 W., in a hill which is also known as Round Mountain. The body of the hill is of dark argillaceous shale capped by sandstone. The rocks are identical in age and character with those of the White County section, except that thus far no coal beds have been found in the Faulkner County hill. This hill rises between 250 and 300 feet above the valley and is nearly a mile long.

In secs. 11 and 14 of the same township and range there is another shale hill that is identical in structure and character with the one just mentioned, though somewhat smaller and only about half a mile long.

CLAY DEPOSITS.

CLAY SHALES.

In addition to the localities specified above as containing large and accessible clay shale deposits, it should be remembered that the parallel valleys of White, Faulkner, and Conway counties are, for the most part, underlain by clay shales, many of which are available as refractory materials for various uses.

In the highlands the brick clays are most abundant in the shale valleys. The valley lying just northwest of Searcy and swinging north and northeast in the vicinity of Center Hill and opening into the Red River Valley east of Mount Pisgah may be taken as typical of those shale valleys of the county in which considerable deposits of brick clays have accumulated. In places these clays are spread out in thin beds for miles over the valley, in others the beds are from 10 to 20 feet thick, while in still other small areas they are entirely absent.

Along some of the larger streams, such as Red River, Big Indian Creek, and Bayou des Arcs, the bottom lands are largely buckshot clay with alluvial soil adjacent to the streams. In the immediate valley of Cypress Bayou good brick clays are abundant, especially about the headwaters of that stream and in the vicinity of Round Mountain, in T. 5 N., R. 10 W.

In the region of the lower hills the brick clays are at many places of great thickness. The following is a section of a well bored near Pangburn post-office, in the northwest corner of the county, in the NE. ¼ NE. ¼ sec. 10, T. 9 N., R. 8 W. This record was kindly furnished by Dr. F. L. Shaw, of Pangburn.

Section of well near Pangburn post-office.

	Feet.
Brick clay	16
Hard sandstone	4
Black shale	70
Hard blue sandstone	4

The western part of White County is mountainous, and on the highest elevations the brick clays, although not altogether wanting, are not so thick or abundant as in the lower lands.

TERTIARY AND QUATERNARY CLAYS.

From Cypress Bayou to Bradford the St. Louis, Iron Mountain and Southern Railway runs through White County just east of the line of junction between the Carboniferous hills on the west and the Tertiary and Quaternary deposits of the lower flat country to the east. This line divides the county into two sections which differ widely from each other in geologic age and in character. The clays of the two areas also differ more or less. Those of the hilly region are derived directly from shales by decomposition. The clays in the lowlands and valleys are the products of the erosion of the higher points, while the clays of the lowlands farther east are often horizontally stratified. Good brick clays are abundant in various parts of White County, especially along the line of the St. Louis, Iron Mountain and Southern Railway.

The Tertiary and Quaternary clays along the Iron Mountain Railway are, according to Mr. Kennedy, made up of two divisions. The upper division is a brownish-yellow sandy clay of very nearly the same texture throughout. In places it has a greater proportion of clay; in others it is nearly a sandy loam, while in still others it is a clean sand. It varies also in color from a brownish yellow to dark orange, or even red.

The second or underlying division is usually a dark-bluish clay, somewhat brownish when damp and weathering almost white when dry and exposed for some time. In some places this clay is of a reddish color, owing to the presence of a greater quantity of iron. Although this lower bed is somewhat lighter in places, it does not materially vary in texture or composition, and wherever found in the region as red, white, or blue clay it is essentially the same material, has the same qualities, and is available for the same uses. In comparing the well records in the district these variations in color have to be taken into consideration, for observers may report the same beds as having different colors.

These two deposits vary considerably in thickness in different parts of the county. The underlying bluish-white clay is persistent over the whole area, but the brownish-yellow clay, overlying the blue, is by no means so extensive and is at some places altogether absent. In the Beebe district the brownish-yellow surface material varies from 3 to 6 feet in thickness. At Searcy it is 3 feet thick, while a mile west of Searcy, in a well, it is only 2 feet 6 inches thick, and it has the same thickness (2 feet 6 inches) at Judsonia.

Wells in the neighborhood of Kensett show that the upper clay there is very irregular in thickness, while in some of them it is wanting altogether. In the Briggs well, in the S. ½ NW. ¼ NE. ¼ sec. 16, T. 7 N., R. 6 W., it is 2 feet thick. On the road near Captain Moseby's house, about a quarter of a mile south-southeast of Moseby's gin house, in the NW. ¼ NW. ¼ sec. 15, T. 7 N., R. 6 W., it is 3 feet thick. At West Point an extensive area is altogether devoid of any such covering, while the railway from that place to Kensett shows it in various places to have a thickness of 2 to 4 feet.

Brownish-yellow clay or earth suitable for the manufacture of brick is found in spots throughout the area under consideration, but most of these areas are too small to be shown on a small map. These spots occur in rolls or on the tops of ridges, and may, as at Judsonia, occupy parts of secs. 8, 9, and 17. At Searcy the brownish-yellow earth extends over an area that is possibly a quarter of a mile wide and three-quarters of a mile long, occupying the small valley running west from the town of Searcy through the centers of secs. 10 and 9 and the middle of sec. 8, T. 7 N., R. 7 W. This area includes the best brick clays in this neighborhood.

The sections exhibited in the well borings from Cabot, Beebe, Kensett, and Judsonia, in a continuous line, as well as those along the lines from Searcy to West Point, show the persistence of the underlying bluish-white or bluish-brown clay. This clay is dark bluish brown when moist and gray when dry. The light-gray appearance is due to patches of pale-blue clay embedded in the mass. When exposed at the surface and allowed free contact with the rain these whitish or pale-blue spots become fluid and spread over the face of the cutting, giving the whole a light appearance. This clay contains also numerous patches stained with iron and some almost black. The following sections show the relations between the upper yellow loam deposits and the lower blue clays and sands:

Section in C. Essig's well, near Beebe.

	Feet.
1. Surface clay	4
2. Bluish clay with dark-colored and iron-stained patches	10
3. Joint clay	20
4. Yellow sandy clay	14
5. Quicksand	7
	55

No. 1 of this section is used for bricks and No. 2 for drain tile.

In the W. ½ N. ½ NE. ¼ NW. ¼ sec. 8, T. 5 N., R. 8 W., a well dug by Mr. Parker gives the following:

Section in Parker's well.

	Feet.
Yellow loam	6
White joint clay	12
Red sandy joint clay with pebbles	35
	53

W. A. Ballou has a well at Beebe 20 feet deep, which shows—

Section in Ballou's well.

	Feet.
Yellow clay	3
Bluish clay	17
	20

Part of the upper division of the lower bed is dug and mixed with 3 feet of yellow clay for brick clay, and the articles so made burn better and are much harder than those made from the yellow brick earth alone.

That part of White County lying east of the St. Louis, Iron Mountain and Southern Railway has not been examined except at West Point. The general geology of the region, however, is inferred to be very nearly identical with that of Lonoke and Prairie counties. Good brick clays are likely to be found throughout most of the eastern part of White County. In the wet lands or slashes the limonite buckshot is found in the clays a short distance below the surface, and, as is well known, these nodules injure clays more or less for brickmaking purposes. The best brick clays of White County are found on the higher lands.

CLAY INDUSTRY.

The upper yellow clays are made into bricks at Beebe, Searcy, and Judsonia, and a mixture of the yellow and upper portion of the bluish clay is also used. The blue clay beneath was formerly also used by Mr. C. Essig at Beebe for the manufacture of drain tiles. The Beebe clay makes hard, solid bricks, but their color is not satisfactory and they can not therefore be used for facing and other purposes where ornamental or fine bricks are required. Their color when properly burned is a light gray, sometimes running into a dark cream, but they are not of a uniform shade. These bricks are well adapted for use in foundations where a sound, hard brick is required without regard to its roughness of appearance or poor color.

When the brownish-yellow upper bed is used alone the clay is worked in a very soft condition and in drying shrinks considerably and shows a tendency to warp. A mixture of the two clays forms a brick which, although coarse, is of good quality, and is less liable to shrink or warp. The mixing of the clays, however, requires a great amount of care and time. The material of the lower bed must be dug up and allowed to lie for some time before it is incorporated with the upper clay.

If the clay were dug from the lower bed during the fall of the year and left exposed to the disintegrating influences of the rains and frosts of the winter and spring its texture for brick or tile making purposes would be materially altered and improved. By such treatment it would be pulverized, mellowed, and almost completely tempered, and with slight additional treatment could be manufactured into bricks of a bright-red color, more uniform than those made from the upper bed alone, and of better texture than those made either from the upper clay or from a mixture of the two.

As a material for the manufacture of drain tiles this winter-mellowed clay would serve a very good purpose. It would turn out a stronger tile than any at present used.

In May, 1905, Mr. J. Y. Woodson was operating a brick plant at Searcy, one-half mile west of the court-house. The yellow surface clay is used to a depth of 3 feet. The mud is pugged in a ring pit with a Raymond wheel run by horse power, and must be ground for one and one-half to three hours before it can be molded. In the summer, when the clay is dry, it requires 200 to 250 gallons of water to temper sufficient mud to make 1,000 bricks. In the winter it requires less than half that amount of water.

The bricks are common wet-mud bricks molded by hand and dried in racks in the open air. They are burned in up-draft kilns of 200,000 capacity. Wood is used for burning, and about three-fifths of a cord is used for each 1,000 bricks. The bricks require twelve to fourteen days for drying and six to eight days for burning. The plant is operated by six men and three boys, and the output is about 5,000 bricks a day.

WOODRUFF COUNTY.

GENERAL GEOLOGY.

The surface of the western half of Woodruff County is composed of the alluvial bottom lands of White and Cache rivers. The surface of the eastêrn half varies from a reddish clay to sandy prairie land, 25 to 30 feet higher than the bottoms of Cache and White rivers. The prairie area is cut into north-south ridges by Bayou de Vue, Buffalo Creek, Caney Creek, and other small streams. The most prominent of these ridges is Nubbin Ridge, which has a north-south trend through R. 2 W. The top of this ridge is 25 to 30 feet above the Cache River bottom to the west. The soil on Nubbin Ridge is much poorer than the rich alluvial soils of the bottoms to the east and west.

The geologic strata of the county belong to two distinct periods. The bottom lands are all alluvial sands, which are now being formed by the present streams. The prairie lands and ridges belong to a much earlier period in Quaternary time.

Where the railroad passes up to Nubbin Ridge from the bottom land just south of Colona the cut shows the following section:

Section of Nubbin Ridge near Colona.

	Ft.	in.
Soil		10
Reddish to yellowish-tinted loamy clay, containing buckshot concretions; practically impervious to water	2	2½
White sandy clay, sharply separated from the above by its lack of moisture, and grading down into a reddish resistant sand, and this to a purple loose sand	10	

The same order of strata that is given above is seen in the road a short distance west of Powell.

The typical prairie lands in the western part of St. Francis County extend westward into Woodruff County. The following section was obtained in wells at Hunter:

Section of wells at Hunter.

	Ft.	in.
Soil (a few inches) at top.		
Red clay, sticky and soft when wet	2	6
White clay		3-6
Hardpan (clay)	9-15	
Clay and yellow sand, very hard when dry	5	
Fine gray sand	5	
White sand	4	
Quicksand with some gravel, water bearing	3	
Hardpan	3	
Sand becoming coarser at bottom, water bearing	35-45	

CLAY INDUSTRY.

At present there is but one plant in Woodruff County where clay is utilized. This is a common wet-mud brick plant located at Cotton Plant. The bricks are made from the yellow loam which occurs in the prairie section of the county. There are no large towns in the county except Augusta, which is located in the alluvial sands of White River, so that the local demand for building brick is not great.

YELL COUNTY.

GENERAL GEOLOGY.

The general geology of Yell County is similar to that of Pope and Logan on the north and to that of Scott and Logan on the west. The clays therefore fall naturally into the same classes, namely, (1) Carboniferous shales and clays interbedded with the hard rocks in place; (2) brick loam and buckshot clays; (3) terrace clays along Arkansas River; (4) clays of the Arkansas River flood plains.

CLAY DEPOSITS.

CARBONIFEROUS CLAY SHALES.

In Yell County the great shale member at the top of the Atoka formation is again one of the most prominent and important of the Carboniferous rocks. This shale enters Yell County on the west, on the south side of Magazine Mountain 2½ miles west of Waveland, and extends along the south side of both Magazine and Chickahah mountains. At the east end of Chickahah Mountain it runs round the end and then, turning westward, extends along the base of the ridge until it joins the same outcrop around the base of Huckleberry Mountain. The same beds run entirely around Three Knobs Mountain, around Spring Mountain, and around Mount Nebo. The shale bed underlying the sandstone on the south side of Dardanelle Ridge is this same shale.

Shales lower in the geologic scale are exposed over a large part of Yell County. At Chickahah village and in the valley thereabout there are many exposures of such shales. At Danville shales are well exposed along Petit Jean Creek with a dip N. 60° W., varying from 20° to 24°. These shales extend over the flat valley for miles east of Danville. On the Rover road south of Danville and on the north side of Danville Mountain there are many exposures of clay shales interbedded with sandstones, and these alternations of shale and sandstone continue to the top of Danville Mountain. Along the road running from Danville to Ola, along the base of the mountain, the rocks are nearly all shales and all dip toward the north. At Ola, on the Choctaw Railway and just south of the railroad station, is a cut, 12 feet deep, in shales. A few hundred feet west of the station there is a large exposure of promising looking shales in the railroad cut. Along the road leading from Ola toward Dardanelle shales are exposed at many places for a mile or more, all of them dipping northward. Where the Ola-Dardanelle road crosses Petit Jean Creek the flaggy shales dip N. 80° E. at an angle of 14°. On the ridge a mile north of Dardanelle the red clay is underlain by fissile shale dipping north and passing beneath Dardanelle Rock.

BRICK LOAM AND BUCKSHOT CLAYS.

The brick loam or yellow and ashen buckshot clays cover a large area in the lowlands of Yell County; indeed, there is probably more clay of this kind in Yell than in any other county in the State. The clays are especially abundant and thick along Petit Jean Creek from the point where that stream enters the county, 3 or 4 miles southwest of Waveland, to the place where it empties into Arkansas River—a distance of about 50 miles. In places south of Dardanelle the yellow loam is exposed to a depth of fully 12 feet, yet the total thickness of the deposit is not visible.

The following are a few localities at which the brick loam has been noted: On the upper Dardanelle-Danville road 3 miles from Dardanelle, at a place where the road crosses the stream, the loam is 6 feet thick, with sandstone fragments at the base. It is a widespread deposit in the lower parts of the valley between Chickahah and Belleville and between Belleville and Danville. The valley soil about Danville is mostly the "buckshot" loam. In many of the low red-clay hills along Harris Creek several feet of yellow clay lies beneath the red clay, and waterworn pebbles beneath the yellow. At Johnsons Bridge, on the lower Dardanelle-Danville road 1 mile southwest of Dardanelle, the yellow loam is at least 12 feet thick. This exposure is especially interesting because it exhibits the relations of the chocolate clays of the river country. The following is the section:

Section at Johnsons Bridge.

	Feet.
Greenish-yellow loam with some waterworn cobbles	4
Chocolate clay with calcareous concretions and nodules	4-8
Yellow sandy clay with calcareous matter in crevices	12

The demarcation between the chocolate clay and the underlying yellow sandy clay is very clear at this locality. The lower bed is deeply scored by big gullies that are in places as much as 12 feet deep. The calcareous matter of the lower bed is derived from that of the chocolate clay by solution and redeposition, as is indicated by the fact that the concretions of the lower bed occur mainly in cracks and are not disseminated through the mass as they are through the chocolate clays.

The following section is an analysis of the lower yellow clay of the Johnsons Bridge section:

Analysis of the lower yellow clay at Johnsons Bridge, 1 mile south of Dardanelle.

[Specimen dried at 110°-115° C. J. P. Smith, analyst.]

Silica (SiO_2)	74.48
Ferric oxide (Fe_2O_3)	7.52
Alumina (Al_2O_3)	11.58
Lime (CaO)	.64
Magnesia (MgO)	.26
Manganese oxide (MnO)	.41
Potash (K_2O)	1.10
Soda (Na_2O)	.54
Loss on ignition	4.11
	100.64
Water at 110° 115°C	1.83

TERRACE CLAYS ALONG ARKANSAS RIVER.

Certain clays and silts along Arkansas River are quite different from any found in the Paleozoic region away from that stream. Such are the loams used for the manufacture of common bricks at

Argenta and at Fort Smith. The same clays occur in Yell County in the second bottoms, usually well away from the river. But as the Yell County line follows this river for 28 miles, there is an abundance of this material in the second bottoms, especially between Dardanelle and the mouth of Petit Jean Creek. Over the pink and yellow clays that form most of these terraces lie patches of what the Arkansas Geological Survey has called chocolate clays. These chocolate-colored clays are very fine silts, and are extremely plastic and sticky when wet. When dried they often break up in small angular and conchoidal fragments and are sometimes called "buckshot" clays, not on account of the presence of the iron nodules that characterize the true "buckshot" loams, but because it falls to pieces in these small lumps about the size of a buckshot. These chocolate clays have thus far been found in the State only within the area subject to overflow by Arkansas River, and it has therefore been supposed that they are silt deposits made by that stream. The section at Johnsons Bridge just given shows that the chocolate clay is of later age than the yellow and pink loams of the second bottoms. The chocolate clay usually contains an abundance of lime nodules. The clay itself is also high in lime, as is shown by the following analysis:

Analysis of chocolate clay from Johnsons Bridge, near Dardanelle.

[Specimen dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	56.91
Iron (Fe_2O_3)	6.68
Alumina (Al_2O_3)	19.80
Lime (CaO)[a]	4.76
Magnesia (MgO)	.96
Potash (K_2O)	2.12
Soda (Na_2O)	1.05
Loss on ignition	9.57
	101.85
Water at 110° 115° C	7.77

A qualitative examination of the nodules in the chocolate clay showed that they consist chiefly of lime carbonate, but they contain considerable iron and magnesium.

The chocolate clay overlying this yellow sandy clay at Johnsons Bridge and elsewhere in the neighborhood has been tried for brickmaking, but without success. Indeed, it may be set down as a rule that the chocolate clay, wherever found in the State, is unsuited to brickmaking.

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[a] Some of the lime is in the form of carbonate, but the carbonic acid was not determined.

ALLUVIAL CLAYS ALONG ARKANSAS RIVER.

The clays of the great flood plain of Arkansas River are confined to the river bottoms proper. They are for the most part extremely variable in character and thickness and hold out but little promise of being useful as clays.

CLAY INDUSTRY.[a]

POTTERY.

In the SE. ¼ SE. ¼ sec. 12, T. 6 N., R. 21 W., a deposit of light-bluish, red-streaked clay overlies the black shales to a depth of 3 to 5 feet. This same clay covers the greater part of the section. Some years ago it was worked as a pottery clay, and was manufactured into a strong, dark-red earthenware. When glazed the material used for the purpose was broken glass and soda, which gave the ware a peculiar greenish color. This clay may be suitable for sewer pipes or any ware requiring a strong plastic clay capable of burning to the verge of vitrification and taking a salt glaze.

In the E. ½ SE. ¼ sec. 11, T. 6 N., R. 21 W., soft blue argillaceous shales appear to underlie 3 feet of broken red shales and sandstones.

COMMON BRICKS.

In the NE. ¼ NE. ¼ sec. 1, T. 6 N., R. 21 W., bricks have been made from a light-yellowish sandy clay. This clay is about 2 feet thick and overlies a red clay. The red clay forms the surface soil in the northern part of the same section and also in part of the NW. ¼ NW. ¼ sec. 6, T. 6 N., R. 20 W. No bricks have been made in this yard since 1886. From the broken pieces of brick lying on the yard they appear to burn to a salmon color when soft, and when burned hard are gray and spotted with iron.

On lot 2 of the NW. ¼ SW. ¼ sec. 6, T. 6 N., R. 20 W., bricks were made some years ago by Messrs. Perry & Kimball and afterward by Mr. R. Smiley. A yellowish clay containing small white calcareous concretions was used for the manufacture of these bricks. This clay is unsuited for hand molding, and the bricks were made on a Hotchkiss machine. Owing to the stiffness of the clay and the tendency of the green bricks to crack when exposed to the sun, there was considerable difficulty in drying them until drying sheds were built. Under cover the bricks dried very slowly, but without much loss through breakage. In burning these bricks the firing was kept up for twelve to fourteen days. The shrinkage or settling in the kiln is said to have been considerable, but no reliable information could be obtained on the subject. The eye bricks showed a slight tendency to vitrification and were of a dark metallic-blue color. The bricks were hard and apparently durable, some of them put down in a pavement twelve years ago being still sound. In the SW. ¼ SE. ¼ sec. 29, T. 6 N., R. 20 W., J. F. Nolan burned a few bricks in 1888. The earth used by him is of orange color. The bed is 2 feet thick and extends over an area of 30 acres. The bricks burned hard and range in color from a dark cherry-red to a light gray. The hard-burned bricks are spotted with dark iron stains. The loss at this kiln amounted to about one-third.

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[a] The notes on the clay industries of Yell County were made by Mr. William Kennedy.

The only plant in operation in the county at the present time (1906) is run by William Murphy, at Dardanelle, for making common bricks. No further information concerning this establishment was obtained.

ANALYSES OF CLAYS.

In the table of analyses of pottery, fire, and other clays of Arkansas given on pages 236–237, certain typical clays of Ohio and Missouri are also included for purposes of comparison.

Analyses of pottery, fire, and other clays.

Laboratory No.	Location.	Silica (SiO_2).	Alumina (Al_2O_3).	Ferric oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O).	Loss on ignition.	Total.	Water at 110°–115° C.
	POTTERY CLAYS OF ARKANSAS.										
276	NW. ¼ NE. ¼ sec. 12, T. 2 S., R. 15 W	65.79	23.92	1.94	0.23	Trace.	1.15	1.08	7.07	101.08	1.80
277	NW. ¼ NE. ¼ sec. 12, T. 2 S., R. 15 W	72.44	18.97	1.59	.18	Trace.	1.35	.91	5.39	100.83	1.55
278	NW. ¼ SW. ¼ sec. 12, T. 2 S., R. 15 W	69.95	22.34	1.44	Trace.	.08	1.28	1.18	5.98	102.25	2.34
279	SE. ¼ sec. 2, T. 2 S., R. 15 W	71.09	19.86	1.81	.11	Trace.	1.45	.81	5.67	100.80	1.96
335	NW. ¼ NW. ¼ sec. 1, T. 2 S., R. 15 W	64.49	23.86	2.11	.31	Trace.	.11	1.82	8.11	100.81	2.37
a 338	NE. ¼ NE. ¼ sec. 24, T. 4 S., R. 17 W	73.24	14.61	1.04	0.78				5.33	100.00	2.01
336	NE. ¼ SE. ¼ sec. 18, T. 13 S., R. 24 W	76.33	16.04	1.24	.99				5.40	100.00	2.23
339	NE. ¼ SE. ¼ sec. 18, T. 13 S., R. 24 W	73.87	17.38	1.64	1.46				5.65	100.00	1.92
337	W. ½ SE. ¼ sec. 5, T. 15 S., R. 25 W	75.99	16.12	1.35	1.45				5.09	100.00	1.08
b 340	NE. ¼ NW. ¼ sec. 9, T. 15 S., R. 28 W	74.85	17.20	1.12	1.13				5.70	100.00	1.53
c 328	S. ½ SE. ¼ sec. 27, T. 7 N., R. 30 W	81.61	10.52	2.70	0.32	0.40	0.66	0.57	3.95	100.73	3.86
329	SE. ¼ NW. ¼ sec. 36, T. 10 N., R. 32 W	67.64	21.57	2.48	.27	.62	1.63	.57	5.53	100.31	2.85
	FIRE CLAYS OF ARKANSAS.										
333	NW. ¼ NE. ¼ sec. 34, T. 8 N., R. 26 W	88.66	5.73	2.55	....	.81	....	....	2.25	100.00	1.33
334	Clarksville (in stream opposite college)	53.36	29.96	5.12	.30	1.16	2.69	1.03	7.90	100.52	3.90
b 341	NE. ¼ SW. ¼ sec. 2, T. 12 S., R. 18 W	76.21	16.00	.75	....	1.06	....	....	5.98	100.00	....
b 342	W. ½ SE. ¼ sec. 5, T. 15 S., R. 25 W	75.32	16.75	.92	....	1.87	....	....	5.14	100.00	1.54
343	....do	74.76	15.96	3.44	.51	1.10	2.28		3.95	100.00	3.33
344	NW. ¼ SE. ¼ sec. 18, T. 13 S., R. 24 W	72.48	18.24	1.52	Trace.	....	1.98	....	5.78	100.00	1.69
345	NE. ¼ NE. ¼ sec. 24, T. 4 S., R. — W	72.59	16.08	1.18	Trace.	.26	3.55		6.34	100.00	2.18
347	SW. ¼ NW. ¼ sec. 4, T. 7 N., R. 18 W	90.49	5.22	1.38	....	....	....	....	3.12	100.00	1.60
352	SE. ¼ SW. ¼ sec. 12, T. 10 N., R. 26 W	62.92	23.60	3.17	.23	.57	2.77		6.74	100.00	2.65
99	SW. ¼ NW. ¼ sec. 16, T. 9 N., R. 31 W	64.63	23.71	3.71	.31	.41	2.03	0.94	6.52	102.26	3.02
351	NE. ¼ NW. ¼ sec. 14, T. 12 S., R. 18 W	79.42	13.35	2.17	Trace.	....	....	....	5.38	100.32	3.72
286	Mabelvale station	65.27	18.75	7.34	.81	1.26	1.10	1.81	6.88	102.22	9.46
d 110	Towson road, Fort Smith	58.43	22.50	8.36	.32	1.14	2.18	1.03	6.87	100.83	3.37
267	Iron Mountain Rwy., near Mount Ida wagon road	62.36	25.52	2.16	.51	.29	1.90	.66	5.32	98.72	1.99
e 270	Faulkner County	64.04	21.55	5.01	.59	.96	1.51	.80	5.94	100.40	1.36
71	Harding & Boucher's quarry, Fort Smith	57.10	23.74	8.18	.53	1.04	1.53	.87	7.21	100.20	4.29
	NW. ¼ SW. ¼ sec. 28, T. 8 N., R. 28 W	65.12	19.05	7.66	.34	.31	1.23	.85	6.12	100.68	4.79
	SUNDRY CLAYS OF ARKANSAS.										
f 51	**Johnsons bridge**	56.91	19.80	6.68	4.76	.96	2.12	1.05	9.57	101.85	7.77
174	**Fort Smith**	76.26	11.74	4.54	.39	.79	1.28	.98	3.82	99.80	3.71
g 330	**River deposit**	70.95	12.24	4.73	1.90	.97	1.14	.66	7.01	99.00	4.19

343	W. ½ SE. ¼ sec. 5, T. 15 S., R. 28 W	74.76	13.96	3.44	.51	1.10	2.28		3.95	100.00	3.33
[f] 274	Union depot, Little Rock	70.05	14.56	6.20	.74	1.12	Not determined.		4.45	97.12	4.48
280	NW. ¼ sec. 30, T. 1 N., R. 11 W. (on railroad)	90.38	4.48	2.10	.16	Trace.	0.41	0.66	1.91	100.10	1.91
173	Railway at Ketchum Iron Co.'s works	83.83	9.32	2.64	.34	.45	1.27	.85	2.40	101.10	2.21
117	South end of railway to Dardanelle	76.20	12.41	4.36	.49	.54	1.21	.84	3.75	99.80	4.06
335	NE. ¼ SW. ¼ sec. 15, T. 1 S., R. 14 W	82.45	11.80	.80	.31	.25	1.60		2.79	100.00	.21
[h] 332	Albany (slip clay)	58.05	14.86	6.76	6.61	3.08	1.18	0.90	7.41	98.75	1.66
	CLAYS FROM OHIO AND MISSOURI.										
[i] 109	Carboniferous shales from Akron, Ohio	60.05	20.00	6.82	.52	.45	1.79	1.60	6.96	98.19	1.25
[j] 264		73.77	17.40	1.88	.49	.31	.61	1.55	5.41	101.42	1.10
311	Cheltenham, Mo.[k]	56.86	28.07	5.03	.27	.32	.11	.96	10.88	102.50	3.84
312		54.92	22.71	9.81	.52	2.59	3.16	.62	5.88	100.21	2.69

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[a] Pink clay.

[b] Slight trace of lime.

[c] Slight trace of manganese.

[d] Sulphur, 0.16.

[e] Sulphur, 0.14.

[f] Chocolate clay; brick clay.

[g] May be used as slip clay.

[h] Used as a slip for black glazing by all potters in the State.

[i] Sulphur, 1.95; used at Akron, Ohio, for the manufacture of sewer pipes.

[j] Sulphur, 0.08; pottery clay.

[k] Used by the Laclede Fire-Brick Manufacturing Company, St. Louis, Mo.: No. 311, for making fire bricks; No. 312, for making sewer pipes.

PRODUCTION.

There has been a steady increase in value of the clay products in Arkansas since 1899, as the following figures will show:[a]

Value of clay products of Arkansas 1899–1907.

Year.	Amount.	Year.	Amount.
1899	$339,142	1904	$696,582
1900	381,012	1905	643,956
1901	407,263	1906	532,194
1902	520,178	1907	536,286
1903	589,946		

The output and value of the various clay products of Arkansas for the year 1907 are summarized below. The number of operating firms reporting is 52.

Quantities and values of various clay products of Arkansas in 1907.

	Quantity.	Value.	Average price per thousand.
Common brick	68,463,000	$468,706	$6.85
Vitrified brick		([b])	10.00
Front brick	1,010,000	11,940	11.82
Fire brick		([b])	12.36
Drain tile		5,160	
Earthenware and stoneware		16,950	
Miscellaneous [c]		33,530	
		536,286	

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[a] Statistics of the clay-working industries in the United States in 1904, by Jefferson Middleton.
[b] Included in "Miscellaneous" to avoid disclosing the operations of individual establishments.
[c] Includes vitrified and fire brick, hollow building tile or blocks, etc.

LIST OF CLAY WORKERS.

The following table gives a directory of the clay workers in Arkansas in 1906, together with the location of their plants and data concerning materials, processes, etc.

List of clay workers in Arkansas, 1906.

Location of plant.		Name of firm.	Material used.	Process.	Drier.	Kilns.		Product.
County.	Place.					Number.	Kind of draft.	
Arkansas	Stuttgart	H. C. Bruner	Surface loam					Common bricks.
Ashley	Hamburg	Nolley Bros						
Benton	Bentonville	Bentonville Brick and Tile Co.						Do.
	do	Thomas Haney	Surface clay	Wet mud	Open air		Up	Do.
	Rogers	J. E. Gelabert & Son	do	Hand	do	2	do	Common builders.
	Siloam Springs	W. S. Williams	Common clay	do	Sun		do	Do.
	Sulphur Springs[a]	David J. Young	Shale	Dry press	Air		Up and down	Face bricks.
Boone	Harrison	J. Samuel Tyson						
Bradley	Warren	Moore & Gannway						
Clark	Arkadelphia	W. A. Obaugh	Surface clay	Wet mud	Sun	2	Up	Common bricks.
	Bradshaw	J. A. Ross						
	Gurdon	N. R. O'Neal	Surface clay	Wet mud	Standard	3	Up	Common builders.
Clay	Pratt[b]	Pratt Brick Co						
Cleveland	Kingsland[c]	Leali Presser and Fire Brick Co.	Shale and surface clay.	Stiff mud and dry press.	Standard	7	Up and down	Fire and common bricks.
Columbian	Magnolia	McIntyre & Co	Red surface clay	Wet mud, handmade.	Sun	1	Up	Common bricks.
Craighead	Jonesboro	Barton Lumber and Brick Co.	Yellow clay	Soft mud and dry press.	Pallet and rack		do	Do.
	do	Jonesboro Brick Co	do	do	do		do	Do.
	do	Logan & Collins						
	do	Patrick Bros. Brick Co	Reworked loess	Wet mud	Pallet and rack		Up	Do.
	do	Sachs Brick and Tile Co	do	Wet mud and dry press.	Closed sheds with steam.		Down	Tile and common building brick.
Cross	Wynne	Wynne Brick Co.	Yellow clay	Soft mud	Pallet and rack		Up	Common bricks.
Drew	Monticello	J. H. Blythe, Drew Brick Co.						
Faulkner	Conway	J. W. Firestone	Surface clay	Stiff mud	Shed	2	Up	Common builders.
Green	Paragould	Paragould Brick Co	Reworked loess	Solt mud and dry press.	Pallet and rack		do	Do.
Hempstead	Doyle	L. F. Huddleston						
	Hope	Hope Brick Works	Surface	Wet mud	Pallet and rack	3	Up	
	Spring Hill	Spring Hill Pottery Co	White Tertiary clay		Closed shed		Down	Stoneware.
Hot Spring	Malvern	Clark Pressed Brick Co	Surface clay	Stiff mud and dry press.	Steam		Up	Common builders.
	Perla	Malvern Brick and Tile Works.	Plastic fire clay	Stiff mud	Direct-heat tunnel	4	Down (round)	Fire, paving, and white front bricks.
Howard	Center Point	M. C. Pope	Red surface clay	Wet mud	Open air		Up	Common bricks.
	Nashville	F. M. Buston						
	do	B. F. Hill						
Jefferson	Pine Bluff	O'Neal & Rogers						
	do	Pine Bluff Brick Co	Surface clay	Soft mud	Standard	5	Up	Common builders; also sand-lime bricks.
	Redfield	James H. Conley	Yellow surface clay	Wet mud	do	1	do	Do.

[a] Office at Fort Smith. [b] Office at Rector. [c] Plant to be removed to Little Rock.

List of clay workers in Arkansas, 1906—Continued.

Location of plant.		Name of firm.	Material used.	Process.	Drier.	Kilns.		Product.
County.	Place.					Number.	Kind of draft.	
Lawrence	Black Rock and Imboden.	Crouch & Courtney	Yellow surface clay	Wet mud	Open air		Up	Common bricks.
	Walnut Ridge	Moore & Co.	do	Soft mud	Pallet and rack		do	Common builders.
Lee	Marianna	O. C. Sutton	Reworked loess	do	do	3	do	Do.
Lonoke	Lonoke	W. H. Harrison	Surface clay	do	Open air	2	do	Do.
	Cabat	I. C. Wylie						
Miller	Texarkana	Interstate Pottery	White Tertiary clay		Closed shed		Down	Stoneware.
	do	Anthony W. Stevens						
	do	Texarkana Brick Co.	Semishale	Dry press		5	Up	Common builders.
Mississippi	Blytheville	Blytheville Brick and Tile Co.						
Monroe	Brinkley	John C. Moshier	Yellow clay	Hand	Open air	2	Up	Common bricks.
Montgomery	Oden[a]	James & Robinson	Residual clay		Closed shed		Down	Stoneware.
Nevada	Emmet[b]	Longston Bros.	Surface clay	Wet mud	Open air		Up	Common bricks.
Phillips	Helena	Straub Pressed Brick Co.	Loess	Wet mud and dry press.	do		Up and down	Do.
Pike	Nathan	C. J. Polk	Residual clay	Wet mud	do		Up	Do.
Poinsett	Harrisburg	Harrisburg Brick Co.	Reworked loess	Soft mud	Pallet and rack		do	Do.
Polk	Mena	Mena Brick Co.	Residual clay	Stiff mud	do		do	Do.
Pope	Atkins	C. B. Wilson	Red surface clay	Hand	Open air	1	do	Do.
	Russellville	Russellville Brick Works						
Prairie	Devall Bluff	Devall Brick Co.	do	Wet mud	Pallet and rack	2	Up	Do.
Pulaski	Little Rock	Arkansas Brick and Manufacturing Co.	Surface clay	Stiff mud and dry press.	Standard and open air.	10	Up (Swift's)	Do.
Randolph	Pocahontas	Jansen & Shannon						
	do	Joseph Schmidt	White and gray clay	Wet mud	Open shed	2	Up	Do.
St. Francis	Forrest City	Choctaw Brick and Tile Co.	Loess	Stiff mud	Pallet and rack		do	Common building bricks.
Saline	Benton	Benton Brick Manufacturing Co.	Surface clay	Soft mud	do		Up and down	Common bricks.
	do	Eagle Pottery Co.	White Tertiary clay		Shed		Down	Stoneware.
Sebastian	Fort Smith	John D. Carbough						
	do	Fort Smith Paving Brick and Fire Clay Co.						
	Mansfield	Choctaw Brick and Gas Co.	Shale	Steam mold	Open air	5	Up and down	Common builders.
Union	Felsenthal	Felsenthal Brick Co.	Red surface clay	Stiff mud	Pallet and rack	4	Up	Do.
Washington	Prairie Grove[c]	Terpening Brick and Tile Co	Surface clay	do	Closed shed	6	do	Do.
	Springdale	J. W. Carter	3 feet surface clay	Hand	Open air		do	Common bricks.
	do	E. T. Caulde	Red surface clay	do	do	2	do	Do.
White	Beebe	Beam & Tidwell	do	Soft mud	do		do	Do.
	Judsonia	Judsonia Brick Co.	do	do	do		do	Do.
	Searcy	J. Y. Woodson	do	do	do		do	Do.
Woodruff	Cotton Plant	H. F. Doyle						
Yell	Dardanelle	William Murphy						Do.

[a] Office at Story.

[b] Office at Sutton.

[c] Office at Farmington.

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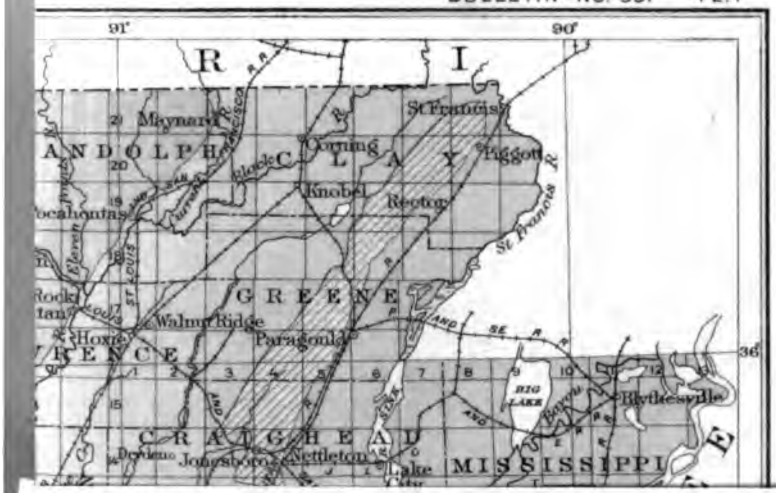
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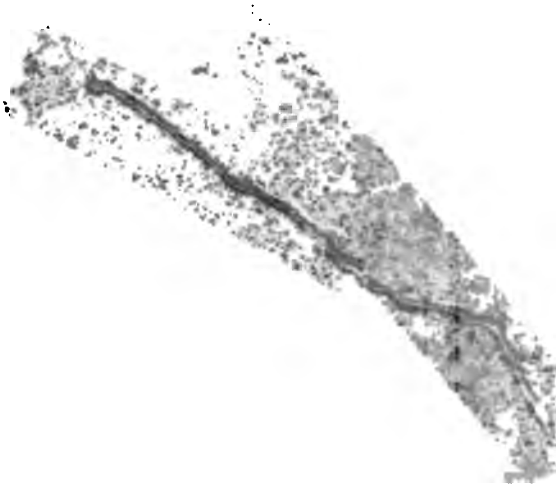

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
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BULLETIN 352

GEOLOGIC RECONNAISSANCE
OF A
PART OF WESTERN ARIZONA

BY

WILLIS T. LEE

WITH NOTES ON THE

IGNEOUS ROCKS OF WESTERN ARIZONA

BY

ALBERT JOHANNSEN

WASHINGTON
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GEOLOGIC RECONNAISSANCE OF A PART OF WESTERN ARIZONA.

By Willis T. Lee.

INTRODUCTION.

Purpose of the investigation.—The investigations described in this bulletin were made in western Arizona under the general direction of Mr. N. H. Darton. The region examined lies mainly west of the high plateau and north of latitude 33° 30′.

The original purpose was to investigate the water resources of the region and the extent to which they might be developed. This necessitated an examination of the geographic features with special reference to irrigable lands and the possibilities of getting water to them, and of the geologic formations with reference to their bearing on questions of underground water. Conditions were found so unfavorable for water development in this region that the economic results of the work are unimportant, or at best have negative value. On the other hand, the region proves to be one of great geologic interest. Many significant features were observed, and their bearing on important geologic problems was noted, but want of sufficient time as well as the desert condition of the region made it impossible to follow out many of the most interesting lines of investigation.

Extent and character of the investigation.—The observations were made during rapid reconnaissance trips. In the summer and autumn of 1903 the Hualpai, Detrital-Sacramento, Big Sandy, Chino, and Aubrey valleys were visited, and Colorado River was examined from Needles, Cal., southward to Yuma, Ariz., the object of the river trip being to examine the geologic conditions at the various reservoir sites of the Reclamation Service along lower Colorado River. During the spring and summer of 1904 a more extended reconnaissance was made, including a river excursion from the mouth of Grand Canyon to Needles, Cal., and several overland trips shown on the accompanying map (Pl. I).

The amount of territory covered necessitated for the most part very general observations, and as the investigation was undertaken in the interests of water development the evident impossibility of development in certain places rendered it impracticable to make extended geologic examinations where such examinations would have been of great scientific interest. For these reasons the fragmentary data here presented might perhaps be of little use if they related to a region fairly well known, but so little is known either of the geology or of the geography of this region that the information, confessedly incomplete, will, it is believed, be of value to many persons.

The northern third of the region is covered by the early reconnaissance maps of the United States Geological Survey, and the geographic features are well known. Little has been done, however, toward accurately mapping western Arizona south of the thirty-fifth parallel. The maps heretofore published were found erroneous, especially in the locations of mountain groups and lines of drainage. It is not claimed that the map accompanying this bulletin is errorless, but in the southern part, where previously published maps have been most incorrect, this map is believed to be measurably accurate owing to data acquired by recent railway surveys and furnished for use in this bulletin by W. A. Drake, engineer of the Santa Fe Railway system.

The geologic formations were mapped where practicable, and their general distribution over the greater part of the region was determined. Data concerning their character and occurrence were collected as far as time would allow, and special attention was given to the recent geologic history.

During the investigation it became evident that changes of a physiographic nature have occurred in recent geologic times, which have produced notable results. Changes in surface elevation and configuration and in climatic conditions have resulted in periods of aggradation and periods of degradation during which nearly the entire region was affected. The evidences of these changes are found in such phenomina as recently formed canyons, filled valleys, aggraded plains, and the deflection of streams.

The chief economic results of the examination have to do with the development of both surface and underground waters. Attention is also called to the mining districts of the region, and certain possibilities of development of the mineral resources are pointed out.

Summary of previous knowledge.—Little information has hitherto been published regarding the geology of this region. In 1856 Jules Marcou's notes were published in the Pacific Railroad Reports,[a] in which he briefly describes the geologic features along the route traversed, including the igneous and granitic rocks of the Truxton Plateau, the detrital filling of the Big Sandy Valley, and the gneiss and lava flows in the region of Williams Canyon. Again, in 1858, he makes brief mention of the region in his "Geology of North America."[a]

---

[a] Marcou, Jules, Pacific Railroad reports, vol. 3, 1856, p. 155.

The first account of any considerable value is found in Lieutenant Ives's report on lower Colorado River, published in 1861. Part 3 of this report, by J. S. Newberry, describes the geology along the route traversed by the Ives expedition. Newberry ascended Colorado River to the mouth of the Virgin, and crossed the northern part of the region from Fort Mohave eastward to the Colorado Plateau. Later, Major Powell, in the course of his exploration of Colorado River, skirted the northern border as far as the mouth of the Virgin, and in the early seventies Gilbert and Marvine described its northern part in the final Wheeler reports.[b]

A few scattered references to the geology of the region are found also in various mining reports. In 1866 [c] Silliman visited certain mines near Fort Mohave, and described in a general way the volcanic rocks of Black Mesa. In 1863 Blake observed a deposit of iron ore near Planet, in Williams Canyon, and described the metamorphic strata with which it is associated.[d] This deposit, together with the copper deposits of the Planet district, have recently been described by McCarn [e] in a brief sketch of the geology of that locality, and Pratt [f] has described the occurrence of ore in the Socorro mine, near Harrisburg, Ariz.

GENERAL GEOGRAPHY.

RELATION TO SURROUNDING REGIONS.

Arizona is divided into three general geographic provinces,[g] known as the Plateau, the Mountain, and the Desert regions. The first province is well known through the writings of Powell, Gilbert, Dutton, Walcott, and others, as the Colorado Plateau; its western limit is very definitely marked in western Arizona by the Grand Wash Cliffs. Between the Plateau and the Desert regions is a mountainous belt comprising the second, or Mountain, region, which includes the greater part of the area described in this bulletin. The third, or Desert, region is mainly one of low-lying plains with more or less isolated mountain groups; it occupies the southwestern part of the Territory.

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[a] Marcou, Jules, Geology of North America, 1858, p. 23.

[b] U. S. Geog. Surv. W. 100th Mer., vol. 3, pts. 1, 2, and 5, 1875.

[c] Silliman, Benjamin, jr., On some of the mining districts of Arizona: Am. Jour. Sci., 2d ser., vol. 41, 1866, pp. 289-308.

[d] Blake, W. P., Iron regions of Arizona: Idem, vol. 40, 1865, p. 388.

[e] McCarn, H. L., The Planet copper mines (Arizona): Eng. and Min. Jour., vol. 78, 1904, p. 26.

[f] Pratt, J. H., Gold deposits of Arizona: Idem, vol. 73, 1902, p. 795.

[g] Ransome, F. L., Description of Globe district: Geologic Atlas U. S., folio 111, U. S. Geol. Survey, 1904, p. 1.

No definite line of separation can be drawn between the Desert and Mountain provinces in the area here described. In central and southern Arizona the distinction is well marked;[a] but in western Arizona the Mountain region, so prominent in the central part of the Territory, becomes a transition belt in which the descent of about 6,000 feet from the high plains of the Colorado Plateau to the low-lying plains of the Desert region of southern Arizona is accomplished through several mountain groups with gradually diminishing elevation. The transition becomes less marked northward until in northern Arizona the change in elevation is accomplished largely by fault scarps.

North of the area described Gilbert, in the Wheeler reports (and other geologists following him), makes but two general provinces, the High Plateau and the Great Basin, but states[b] that on account of an interlocking of characteristics along the borders their common boundary is not easily located. This division into two topographic provinces is a more natural one for northwestern Arizona than the threefold division of central Arizona. The basin ranges and broad gravel-filled valleys of Nevada extend southward into Arizona and bear the same general relations to the High Plateau that they do in southern Nevada and Utah.

TOPOGRAPHY.

General character.—The Colorado Plateau here enters into consideration only in so far as it forms the boundary of the area described. This bulletin is concerned chiefly with the low-lying area to the west.

In the Mountain region, south of the area described, the rocks have been deeply dissected by erosion, and great crustal movements have occurred. Near the escarpments bordering the plateau the mountains consist in some places of disturbed portions of the sedimentary formations of the plateau, let down to their present position by faulting. Mountains of this kind occur in the vicinity of Globe, Ariz.,[c] in the Tonto basin,[d] and within the region described near the mouth of Grand Canyon. In many places, especially at a distance from the edge of the plateau, sedimentary rocks are not found, and it is difficult to determine whether mountains composed entirely of crystalline rock are due to local elevation or are simply masses left by erosion during the general degradation of the region.

---

[a] Lee, W. T., Underground waters of the Salt River valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905.

[b] Gilbert, G. K., and Marvine, A. R.: U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, p. 57.

[c] Ransome, F. L., Description of Globe district, Arizona: Geologic Atlas U. S., folio 111, U. S. Geol. Survey, 1904. Also Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903.

[d] Lee, W. T., Underground waters of the Salt River valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905, p. 117.

The mountain ranges throughout western Arizona, with a few notable exceptions, lie in general parallel to the border of the plateau. In general, also, the mountains become smaller and more completely isolated away from the plateau. In central Arizona, where the distinction between mountain and plain is most marked, rugged mountains extend from Mogallon Mesa to the Superstition Mountains, a distance of 70 miles, where they give place gradually through such isolated groups as the Phoenix Mountains, Estrella Mountains, etc., to the still smaller hills of southwestern Arizona. As the mountains become less prominent the valleys broaden and finally blend into a plain completely surrounding the isolated mountain groups. The topographic character of northwestern Arizona lies between these extremes, the area being about equally divided between mountain and plain.

Mountains.—The mountains of northwestern Arizona occur in four more or less distinct groups. The first consists of a series of cliffs at the eastern border of the region known as the Grand Wash, Cottonwood, Aquarius, and Yampai cliffs. The first three form a practically continuous escarpment, extending from Colorado River southward to Williams Canyon, a distance of about 125 miles. The Grand Wash Cliffs, extending from Colorado River to Music Mountain, a distance of about 50 miles, is composed of crystalline rock at the base, overlain by the sedimentary formations of the plateau region. At Music Mountain this escarpment divides, the lower or crystalline part continuing southward under the names of the Cottonwood and Aquarius cliffs and forming the edge of the Truxton Plateau, while the upper or sedimentary part recedes to the east, under the name of the Yampai Cliffs. With the lower group of cliffs may be included the Aquarius and Artillery mountains, which form the southward extension of the Aquarius Cliffs.

A second group, consisting of the White Hills, Cerbat, and Hualpai mountains and the Aubrey Hills, forms a broken range parallel to the cliffs at the west. The White Hills and the Aubrey Hills are inconspicuous as topographic features, but the two central sections are prominent. The Hualpai Mountains attain a maximum altitude of 8,266 feet in Hualpai Peak, and the Cerbat Mountains an altitude of somewhat more than 7,000 feet in Cherums Peak.

A third group, lying still farther to the west, is commonly known as the Black Mountain Range, and consists of the Black Mountains proper, Black Mesa, and the Mohave Mountains. This range is relatively low, except at its northern end, but is continuous from Colorado River southward to Sacramento Wash, where it is broken down for a few miles before attaining prominence again in the Mohave Mountains.

The fourth group of mountains, situated south of Williams River, does not correspond with the other three groups in geographic position or in regularity of arrangement. In place of the parallel arrangement of north-south ridges just described, this group is made up of three large east-west ranges and three small north-south ranges. The Harcuvar and Harquahala mountains are about equal in altitude and are the loftiest and most massive mountains in central western Arizona. The other groups are less conspicuous, though the Buckskin Mountains are moderately prominent, particularly at their eastern extremity.

Valleys and plains.—Three distinct kinds of lowland occur: First, the valleys and canyons now containing running water, such as the Colorado and Williams valleys, including Big Sandy Wash and Santa Maria Canyon; second, old débris-filled valleys, such as the Detrital-Sacramento, Hualpai, and Big Sandy valleys; and third, plains eroded from hard rock or built up by flows of igneous rock, such as the Truxton Plateau. Extensive detrital plains, such as Cactus Plain, Ranegras Plain, etc., which occur south of Williams River, are probably débris-filled valleys similar to those farther north, but their character is not certainly known.

DESCRIPTIVE GEOLOGY.

ROCK FORMATIONS.

The rocks of western Arizona are mainly pre-Cambrian crystallines, Tertiary eruptives, and probably Quaternary sediments. Sedimentary formations of Paleozoic age occur only at the eastern margin of the area described. The igneous rocks are described by Albert Johannsen (see pp. 81–92), but many of the details upon which this general description is based may be found in the following sections.

PRE-CAMBRIAN.

The oldest rocks of the region consist mainly of granites and gneisses. (See p. 81.) Coarse-grained granitic rock giving little or no evidence of gneissoid structure is found in many places throughout northwestern Arizona. It occurs beneath the Cambrian sandstone at the base of the cliffs in the eastern part of the region, forms the central core of the Black Mountains, and constitutes the main mass of the Cerbat and Hualpai mountains. Gneiss occurs in many places, either in extensive masses, as at the southern end of the Hualpai Mountains and in the Aubrey Hills, or in restricted areas where local movements have taken place, as near Hualpai Wash, at the northern end of the region. At the mouth of the Grand Canyon the granite, which had obviously been exposed at the surface prior to the deposition of the Cambrian sediments, is prevailingly red to a depth of

200 feet or more. A similar coloring of both the granite and the gneiss was noted in Black and Boulder canyons and in several places south of Williams River.

Metamorphosed sediments, consisting of quartzites, argillites, and limestones, occur in several localities in northwestern Arizona. These were observed in Virgin Canyon at the northern end of the region, in Williams Canyon, and in the Granite Wash Hills in the vicinity of Harrisburg. They are highly metamorphosed, faulted, tilted, and more or less included as blocks within the granites and gneisses. They were nowhere observed in contact with the Cambrian, but on account of their high degree of metamorphism and their intimate association with granites which, in the cliffs region, lie beneath the Cambrian sandstone, are here regarded as probably pre-Cambrian rocks.

CAMBRIAN.

According to the various writers who have described the Grand Canyon region, Cambrian rocks occur in Grand Canyon and are identical in character with those in the cliffs in the eastern part of the area described. They consist of a coarse-grained basal quartzite 80 to 100 feet thick, overlain by about 600 feet of yellowish-green arenaceous shale. The quartzite and shale together comprise the greater part of the Tonto formation of the Grand Canyon section.

CARBONIFEROUS.

Resting with apparent conformity upon the Tonto formation is the Redwall limestone (the Devonian of Grand Canyon described by Walcott[a] was not identified in the cliffs), which is 1,000 feet or more in thickness where examined.[b] From Music Mountain southward this limestone is separated more or less distinctly into an upper and a lower division. The upper part is massive, with little tendency toward separation into layers even in weathered surfaces. The lower part, although consisting mainly of limestone, is made up of distinct layers, often separated by thin seams of clay.

In Truxton Canyon two small collections of fossils were obtained from the Redwall limestone. These were examined by G. H. Girty, of the Geological Survey, who reports the following lists.

At Yampai, near the top of the exposed section, the following were obtained:

Derbya? sp.
Composita aff. C. subtilita.
Aviculipecten sp.
Aviculipecten sp.
Aviculipecten sp.
Myalina sp. aff M. meliniformis and M. congeneris.
Edmondia? sp.

---

[a] Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 20, 1880, pp. 221-225.

[b] G. K. Gilbert's section at the mouth of Grand Canyon shows a thickness of 2,675 feet in the Redwall limestone.

These fossils, according to Girty, indicate a Pennsylvanian or "Coal Measures" age.

Lower in the section, near Nelson, Ariz., Mississippian forms were obtained as follows:

Menophyllum excavatum.
Schuchertella inæqualis.
Spirifer centronatus.
Spirifer striatus var. madisonensis.
Straparollus sp.

Girty states that this is the Eomississippian fauna, which has a wide range over the West, correlating with the lower "Wasatch"[a] limestone of Utah, the Madison limestone of Yellowstone Park, and the Chouteau limestone of Missouri.

The Redwall limestone has been described by Gilbert[b] as consisting of "Upper Carboniferous" above and "Lower Carboniferous" below, and King[c] makes a similar division of the "Wasatch" limestone in Utah. It is probable that in the area here described the line of separation between the Pennsylvanian and the Mississippian is to be drawn between the upper massive and the lower laminated divisions of the Redwall.

TERTIARY.

Eruptive rocks.—If sediments of Triassic, Jurassic, or Cretaceous age were deposited in western Arizona, they were removed previous to the opening of the Tertiary period. The Tertiary rocks are principally effusive andesites and rhyolites, which occur in isolated mountain masses and in broad sheets having a maximum thickness of 3,000 feet or more. The oldest effusive rock is the andesite of the northern end of Black Mesa. (See p. 27.) It is a dark-colored porphyritic rock lying above the granite and beneath the rhyolites and later andesites.

The older andesite is overlain by extensive beds of rhyolitic ash, tuff, and flows, which extend over a large part of western Arizona, and which were in turn followed by extrusions of andesite. The rhyolites and younger andesites are closely associated and must at present be described together. (See pp. 83–87.) They are conspicuously exposed in the Black Mesa, White Hills, Kingman Mesa, and Aquarius Mountains, but extend eastward beyond the area mapped, and farther south occur in extensive masses in the Chocolate and Dome Rock ranges.

Some of the older basalt sheets of the region may also belong to the Tertiary, but this is not definitely known. They cut the rhyolites and andesites in dikes and overlie them in sheets. East of Chloride they

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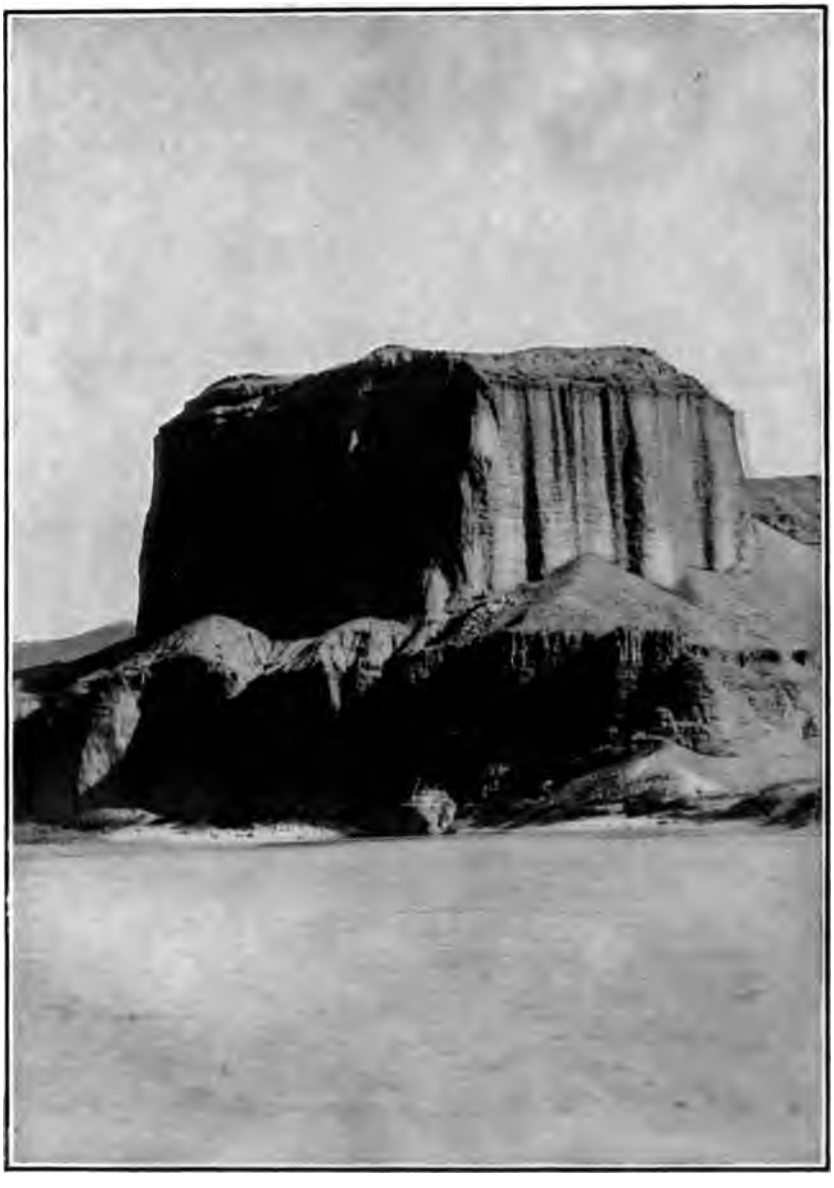
[a] Present usage of the Geological Survey restricts the name Wasatch to the Eocene formation. As soon as sufficient detailed work can be done, another name will be assigned to the Carboniferous formation.

[b] Gilbert, G. K., Final Rept. U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, pt. 1, p. 178.

[c] King, Clarence, Final Rept. U. S. Geol. Explor. 40th Par., vol. 1, p. 155.



TEMPLE BAR CONGLOMERATE AT TEMPLE BAR.

occur within the Detrital-Sacramento Valley, which was presumably excavated in late Tertiary time.

Greggs breccia.—The Greggs breccia, so called from Greggs Ferry, at the northern end of the region, is a name here given to a detrital formation filling the Grand Wash Trough and having an exposed thickness of about 1,400 feet. It is composed of coarse unassorted and poorly stratified material, consisting largely of blocks of crystalline rock, similar to the granite and gneiss of the Virgin Mountains to the west. Toward its top the detrital material is cemented with lime carbonate, and in places the upper 200 feet consists of travertine containing few rock fragments. This travertine is best exposed south of Colorado River and east of Greggs Ferry, where it caps conspicuous cliffs, which rise 1,400 feet or more above the river.

The formation contains no fossils, so far as observed, and its reference to the Tertiary is based largely on the physiographic evidence given in detail in the description of the Grand Wash Trough and later in the section on "Geologic history." Briefly stated, the accumulation of the breccia antedates the cutting of Grand Canyon, which apparently began either in the latter part of the Tertiary or at the beginning of the Quaternary.

QUATERNARY.

Temple Bar conglomerate.—Temple Bar conglomerate is a name here given to a sand and gravel formation having wide distribution in western Arizona. It occurs in the Colorado and other valleys of that region, filling the low places generally to an altitude of 3,000 feet or more. The conglomerate is typically exposed near the mouth of Virgin River at Temple Bar, from which it takes its name. At this point it consists of slightly consolidated sand and gravel exposed in nearly perpendicular cliffs (Pl. II), in which are included sheets of basalt.

Where exposed along the Colorado, the Temple Bar conglomerate is evidently a river deposit, but it merges laterally into deposits of angular mountain wash in some places, and possibly into lacustrine deposits in others. It rests unconformably upon the Greggs breccia and older formations, and is apparently equivalent in age to the widespread detrital accumulation filling the low places of the Southwest generally and forming the desert plains of Arizona and parts of southern California.

No fossils have been found in the conglomerate, and there are no means known at the present time by which it may be definitely correlated with other formations. In composition, geologic and physiographic relations, and general appearance it is similar to the Gila conglomerate described by Gilbert[a] from the Gila Valley; by Ransome[b] from the vicinity of Globe, Ariz.; by Lindgren[c] from eastern Arizona, and by the present writer[d] from the Salt River Valley in central Arizona. The greater part of the Temple Bar conglomerate, however, is not usually so well consolidated as the Gila conglomerate, although in places, especially where the older portions are exposed, it is as firmly cemented.

In constitution and general appearance the formation resembles the Lake Bonneville beds of Utah described by Gilbert[e] as Quaternary. The correlation, however, is based mainly on physiographic evidence, the discussion of which is included under "Geologic history," and, for the sake of clearness, is placed after the section on descriptive details.

Chemehuevis gravel.—Chemehuevis is here applied to a series of gravels that lie unconformably upon the Temple Bar conglomerate in the terraced bluffs along Colorado River from Grand Canyon to the Gulf. In the open valleys south of Black Canyon they form the conspicuous bluffs seen in characteristic development from Bulls Head southward. The name is derived from the Chemehuevis Valley, south of The Needles. The gravels are about 700 feet in maximum thickness, but occupy a measurably narrow belt along the river, having been deposited as valley filling during an aggrading stage of Colorado River. (See p. 65.) Their unconformable relations with the Temple Bar conglomerate and their unconsolidated condition render it probable that they are of late Quaternary age.

Basalt flows.—Included in the Temple Bar conglomerate in many places, and sometimes overlying that conglomerate, are sheets of basalt from a few feet to 800 feet in thickness, in some places occupying large areas. These are younger than the basalts which were described on page 16 as having perhaps been outpoured at the close of the Tertiary and which underlie the Temple Bar conglomerate.

GEOGRAPHIC AND GEOLOGIC DETAILS OF HIGHLANDS.

GRAND WASH CLIFFS.

Location.—The Grand Wash Cliffs, located in the northeastern part of the area described, form an escarpment extending from Music Mountain northward beyond Colorado River. They constitute the boundary between the High Plateau or Grand Canyon district to the east and the low-lying Basin region to the west.

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[a] Gilbert, G. K., U. S. Geog. Surv. W. 100th Mer., vol. 3, pt. 5, 1875, p. 540.

[b] Ransome, F. L., Geology of Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903, pp. 47-51.

[c] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, pp. 75-77.

[d] Lee, W. T., Underground waters of the Salt River Valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905, pp. 111-114.

[e] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890.

Topographic features.—The Grand Wash Cliffs are very precipitous, as shown in section *P-P'*, Pl. V, rising 4,000 feet or more above the plains to the west. The drainage of the plateau near the cliffs is northward to Colorado River, and the continuity of the westward-facing escarpment is broken by few canyons.

The lower or granitic portion of the cliffs, though not so nearly perpendicular as the upper or limestone portion, is steep, and the slopes meet the detrital surface of the Hualapai Valley at high angles. Numerous detrital cones have formed at the foot of the escarpment, but they are comparatively small. In a few places the cones join laterally, forming an alluvial slope, but in general the escarpment rises abruptly from the nearly level floor of the valley.

Rock masses.—At the mouth of Grand Canyon the cliffs are composed principally of Carboniferous limestone (Redwall) and Cambrian sandstone and shale (Tonto), with a little granite exposed at the base. In Music Mountain, at the southern end of the Grand Wash Cliffs, the same series occurs, but the granite is more extensively exposed, the base of the Tonto being about 4,000 feet higher than at the mouth of Grand Canyon.

The granite is coarse grained and is intersected by dikes and sheets of intrusive rocks which terminate abruptly at the contact between the granite and the overlying sandstone of the Tonto. This contact, as seen in the face of the escarpment, is a practically straight line and represents a base-leveled surface upon which the Cambrian sediments were deposited.

The sandstone at the base of the Tonto at the mouth of Grand Canyon is 80 feet thick and the overlying shale is about 600 feet thick. About 12 miles southwest of the mouth of the canyon, at the base of the tilted block through which Iceberg Canyon is cut, the sandstone is again 80 feet thick, but the overlying shale is only 200 feet. A few miles north of Music Mountain, in the pass occupied by the road from the Hualpai Valley to the plateau, the sandstone was found to be 50 feet thick and the overlying shale 300 to 400 feet thick.

The Devonian of the Grand Canyon region, described by Walcott,[a] was not identified by the writer in the Grand Wash Cliffs. The highest formation observed was the Redwall limestone, which forms the rim of the cliffs, and though more or less eroded, still has a thickness of 1,000 feet or more, according to locality.

COTTONWOOD AND AQUARIUS CLIFFS.

Location.—At Music Mountain the escarpment divides, the upper or sedimentary part receding toward the east and the lower or granitic part continuing southward under the names of the Cottonwood and the Aquarius cliffs. The Cottonwood Cliffs extend from Music

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[a] Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 20, 1880, p. 222.

Mountain to Trout Creek, and are best observed in Truxton Canyon, through which the Santa Fe Railway descends from the high plateau to the lowlands farther west. The Aquarius Cliffs extend from Trout Creek southward to the Aquarius Mountains.

Topographic features.—The Cottonwood and the Aquarius cliffs are lower and less precipitous than the Grand Wash Cliffs. Alluvial cones and slopes are developed to some extent at the base of the Cottonwood Cliffs north of Truxton Canyon, but from that canyon southward to Signal the Big Sandy flows close to the cliffs and prevents the formation of cones.

The continuity of the escarpment formed by these cliffs is interrupted in several places by canyons, chief among which are Truxton, White Cliff, Trout, and Sycamore creeks. The canyons are narrow and steep and the streams torrential in character.

Rock masses.—The Cottonwood Cliffs are composed principally of granite, 2,500 feet of which is exposed near Hackberry. The granite is covered by a comparatively thin sheet of andesite which forms the cap rock of the cliffs and thickens southward, connecting with the great masses of igneous rock in the Aquarius Mountains.

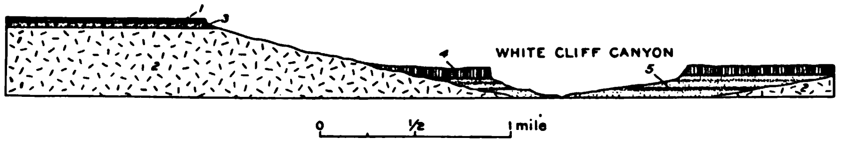


FIG. 1.—Sketch section across White Cliff Canyon, showing relation of the andesite of the Truxton Plateau to the younger basalt at the foot of the cliff. 1, Andesite flow; 2, granite; 3, andesite tuff; 4, basalt flow; 5, stratified volcanic ash.

In White Cliff Canyon the plateau is covered by andesite 200 feet thick, the lower half consisting of tuff and the upper half of a columnar flow. Near the mouth of the canyon a younger mass of volcanic rock occurs in an erosion embayment about 1,200 feet lower than the lava capping the cliffs. The younger mass is basalt and consists of several layers of ash, tuff, and flow. (See fig. 1.)

YAMPAI CLIFFS.

Location.—A series of irregular cliffs extends from Music Mountain in a general southeasterly direction to the southern end of the Juniper Mountains, where they turn northward, forming the western bluffs of the Chino Valley, which lies directly east of the area here described. These are locally known as the Yampai Cliffs.

Topographic features.—The Yampai Cliffs resemble the Grand Wash Cliffs in being precipitous and composed of hard limestone strata, but differ from them in being much more irregular in outline. They vary in altitude from about 6,000 to 6,700 feet and rise 1,000 or more feet above the Truxton Plateau. In their sinuous outlines, large reentrant angles, and detached outlying portions Yampai

Cliffs exhibit the characteristic features of an erosion escarpment, the steep face being maintained by the hard Redwall limestone at the top.

Rock masses.—Pre-Cambrian granite occurs in the base of the cliffs. It was observed by the writer in four localities—at Music Mountain, in Truxton Canyon, near Cross Mountain, and at the southern end of the Juniper Mountains. As in the Grand Wash Cliffs, it terminates above in a base-leveled plain, upon which the Cambrian sediments rest.

The Cambrian rocks described continue uninterruptedly southward from the Grand Wash Cliffs, the basal sandstone being about 100 feet and the shale about 225 feet thick at the southern end of the Juniper Mountains.

The Redwall limestone continues southward as the highest formation of the cliffs, and on account of its superior hardness maintains the precipitous face. It thins southward, probably owing to erosion, until at the southern end of the Juniper Mountains it is only 450 feet thick.

The section near Nelson, in Truxton Canyon, yielded the fossils previously described, showing that the Redwall limestone is partly of Mississippian and partly of Pennsylvanian age. Although examined with considerable care, no fossils were found in the limestone at the southern end of the Juniper Mountains.

TRUXTON PLATEAU.

Location.—Lying between the Yampai Cliffs on the east and the Cottonwood and Aquarius cliffs on the west, is a comparatively level plain extending from Music Mountain southward to the Aquarius Mountains. The writer crossed it in two places near the northern end, as shown by the routes of travel delineated on Pl. I. In the vicinity of Truxton Canyon it is locally known as the Truxton Plateau, and this name may be used to designate the entire area.

Topographic features.—The plateau, which lies about 5,000 feet above sea level, consists of eroded granite, nearly covered with eruptive rock, which fills the depressions, leaving the higher granite points exposed above the lava. In other words, the Truxton Plateau is a lava-covered peneplain which has been slightly dissected by a few streams that have cut narrow canyons. Back from the edge of the plateau these are shallow, but they deepen rapidly as they near the cliffs to the west, a fact indicative of comparatively recent uplift.

Rock masses.—The rocks of the plateau are pre-Cambrian granites overlain by Tertiary rhyolite and andesite, together with basalt of more recent origin. The plateau was not visited south of Trout Creek, but, seen from a distance, the igneous rock apparently extends continuously southward to the great masses of rhyolite and andesite of the Aquarius Mountains.

AQUARIUS MOUNTAINS.

Location.—The Aquarius Mountains, located in the east-central part of the region, form a group of considerable size at the southern end of the Truxton Plateau, and extend in a southeasterly direction across the course of Rio Santa Maria and Date Creek.

Topographic features.—South of the mouth of Deluge Wash the Aquarius Cliffs gradually lose their scarplike character and finally merge into the general westward slope of the Aquarius Mountains. These mountains were visited only at their southern and western extremities, but from the west at a distance they appear as lofty mountains, comparable in altitude with the Hualpai Mountains to the west, and the Harcuvar and Harquahala mountains to the south.

The southern part of the group is carved into rugged, irregular hills. Rio Santa Maria has eroded a narrow canyon deep into the lavas, and smaller streams have cut less deeply. Date Creek has cut through the end of the ridge, instead of following an apparently easy course a few miles farther south.

Rock masses.—The granite of the Truxton Plateau extends southward to the Aquarius Mountains, and was examined in Signal Canyon. The southern part of the group, however, is composed of andesites and rhyolites, presumably of Tertiary age. South of Santa Maria Canyon the mountains, 3,000 to 4,000 feet high, are composed of effusive rock, which has been dissected by erosion to a depth of about 3,000 feet.

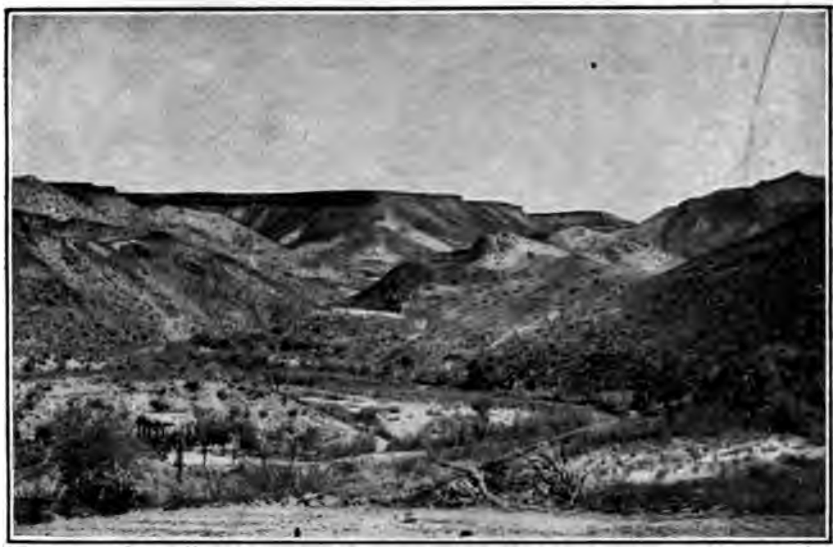
Within valleys eroded in the Tertiary lavas small sheets of basalt occur, in some places capping gravels of probable Quaternary age, as in Signal Canyon (Pl. III, *A*), and in other places occurring within these gravels, as in Santa Maria Canyon near the mouth of Big Sandy Wash.

ARTILLERY MOUNTAINS.

Location.—The Artillery Mountains form a small group near the head of Williams River. They are separated from the Aquarius Mountains by Signal Canyon only, and are virtually an outlying group of those mountains.

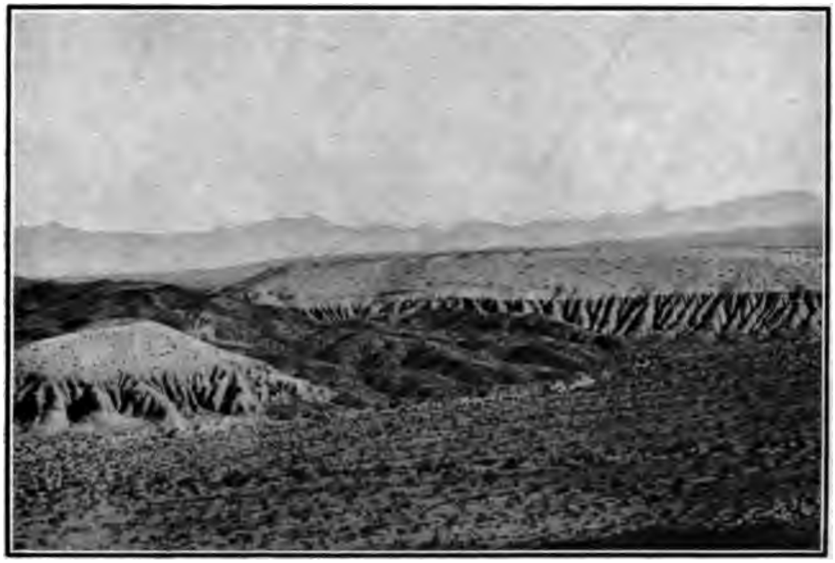
Topographic features.—The Artillery Mountains are small and comparatively low, the only conspicuous peak being a sharp pinnacle of igneous rock, apparently a volcanic neck, which, on account of its altitude and pointed summit, is visible and easily identifiable from great distances. The rocks are deeply dissected by erosion on the east and south near Big Sandy and Williams rivers, but to the north and west the mountain flanks are buried by the detritus of the Big Sandy Valley.

Rock masses.—The main rock mass of the Artillery Mountains is coarse-grained granite, mineralized in places, although the mineral



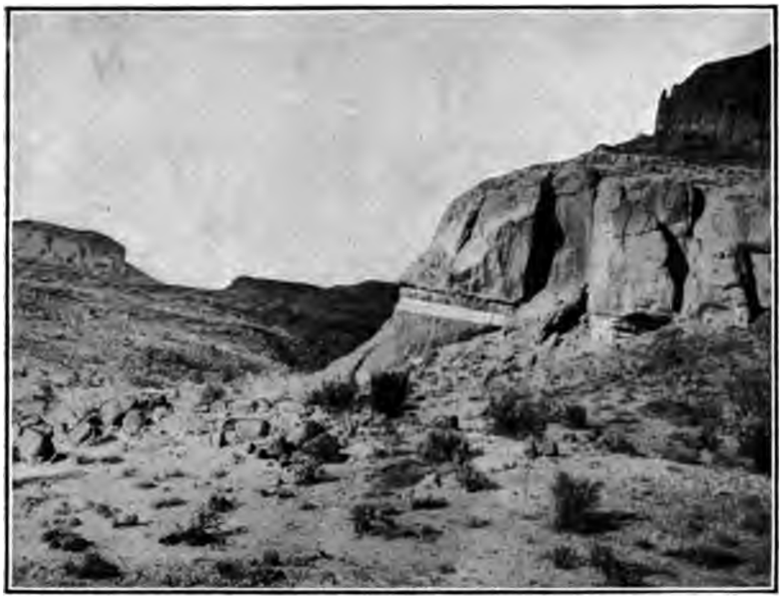
A. SIGNAL CANYON, AQUARIUS MOUNTAINS.

Showing lava-capped gravel and sand filling.

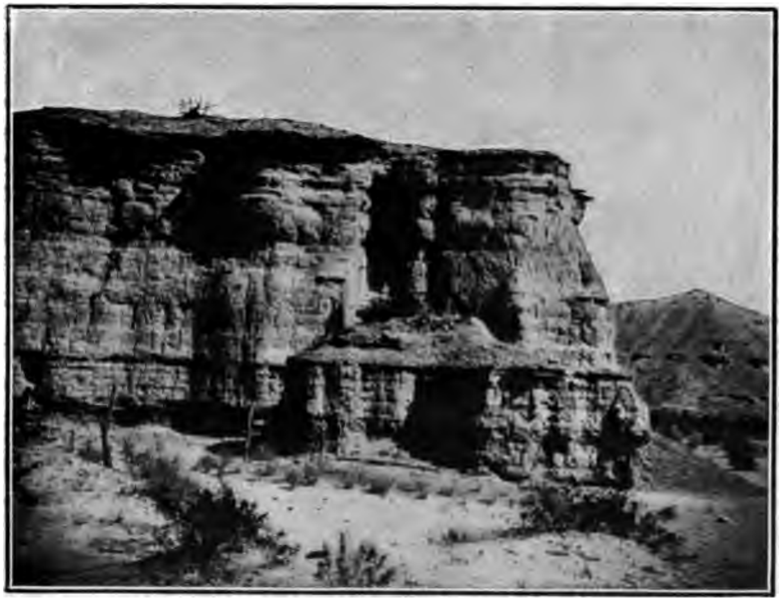


B. CHEMEHUEVIS GRAVEL NEAR BULLS HEAD.

Overlying granite at left. Showing upper and lower divisions of gravel.



A. RHYOLITIC ASH NEAR KINGMAN.



B. DETRITUS AT MOUTH OF DELUGE WASH.

prospects have not been extensively developed owing to the inaccessibility of the region.

Overlying the granite south of Artillery Peak occur thick masses of effusive rock similar in appearance to the older effusives of the Aquarius Mountains to the east, but separated from them by erosion. Quaternary lavas also occur in small quantities included in and overlying the gravels in Signal and Williams canyons.

WHITE HILLS.

Location.—The White Hills, located in the north-central part of the region described, are the southward continuation of the Virgin Mountains of southeastern Nevada, and are separated from them by Virgin Canyon.

Topographic features.—The White Hills consist of many more or less isolated peaks and groups of hills rising a few hundred feet above the plains on either side of them, and are inconspicuous as compared with neighboring highlands.

Rock masses.—Granite similar in general appearance to that beneath the Cambrian formation of the Grand Wash Cliffs occurs in these hills, and is more or less mineralized, several gold prospects having been developed in it. Quartzites and argillites, apparently of pre-Cambrian age, occur in the hills south of Virgin Canyon. The Tertiary rhyolites and andesites are found from Squaw Peak to the southern end of the White Hills, and occur as light-colored beds of tuff and ash and as flow sheets.

CERBAT MOUNTAINS.

Location.—The Cerbat Mountain range, about 30 miles long, lies south of the White Hills, between the Hualpai and the Detrital-Sacramento valleys.

Topographic features.—The mountains are high, attaining a maximum altitude of about 7,000 feet in Cherums Peak, and have been deeply eroded. At the southern end of the range they break down and merge into a dissected plateau.

Rock masses.—The Cerbat Mountains are composed mainly of granitic rock similar in general appearance to the pre-Cambrian granites of the cliffs region to the east. These are intersected and more or less completely surrounded by effusive rocks.

Along the western base of the range rhyolite and andesite occur at intervals, but are frequently eroded away or covered with wash. Near the southern end of the mountains they overlie the granite in extensive beds of ash, tuff, and flow, originally 1,000 feet or more in thickness. The igneous rocks are evidently due to a long series of eruptions, flows, and beds of tuff alternating (see Pl. IV, *A*), and both being cut by dikes and covered by younger effusives.

These effusives are megascopically and microscopally the same as the rhyolites and younger andesites of Black Mesa to the west, and form a part of the lava sheet supposed to have once extended continuously across the Detrital-Sacramento Valley. At the northern end of the range sheets of olivine basalt occur at the crest of the ridge, tilted eastward. (See section *Q-Q'*, Pl. V.) In several places along the eastern base similar sheets occur, dipping steeply to the east and passing beneath the detrital filling of the Hualpai Valley.

Structure.—The eastward inclination of the lava sheets along the eastern base of the Cerbat Mountains suggests an eastward tilting of the surface similar to that shown in Iceberg Canyon to the north and in the Hualpai Mountains to the south (fig. 2).

HUALPAI MOUNTAINS.

Location.—The Hualpai Mountains are situated between the Sacramento Valley on the west and the Big Sandy Valley on the east, in the central part of the area described.

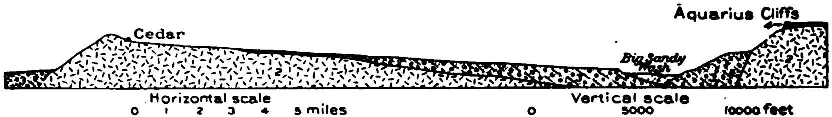
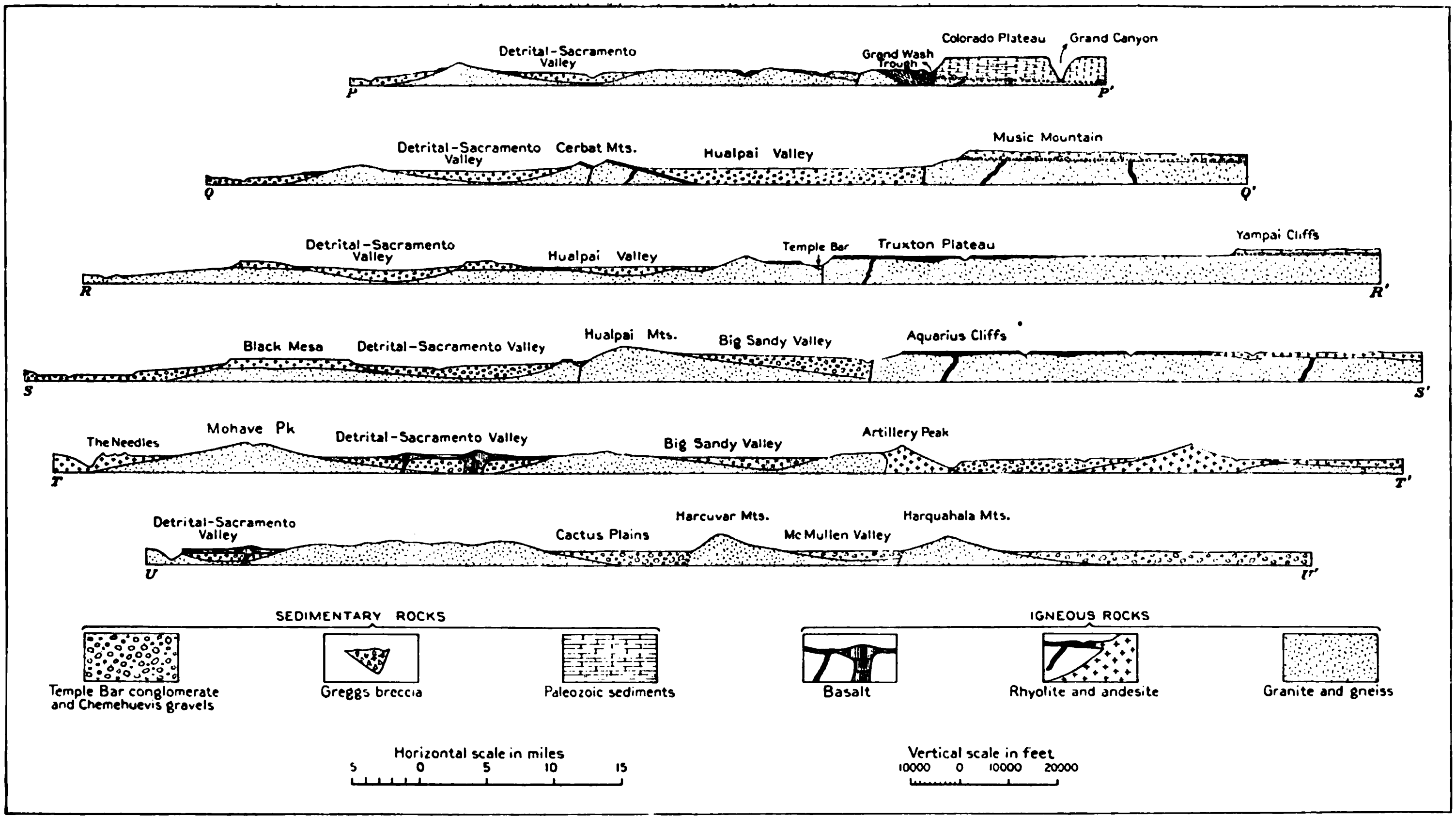


FIG. 2.—East-west section across Big Sandy Valley, showing the tilted Hualpai block and the unconsolidated gravel beds inclined toward the face of the Aquarius Cliffs. 1, Chemehuevis (?) gravel; 2, granite; 3, Temple Bar (?) conglomerate; 4, andesite.

Topographic features.—The range is about 35 miles long, with a general altitude of about 7,000 feet and a maximum altitude of 8,266 feet, attained in Hualpai Peak. The western slope is very precipitous down to an altitude of about 3,000 feet, where it meets the detrital plain of the Sacramento Valley at high angles. Along its base occur small flat-topped lava-covered hills, rising a few hundred feet above the surrounding plain. These are most numerous at the north, near the lava fields of the Kingman area, but extend southward nearly to the southern end of the range. Detrital material has accumulated in alluvial fans and slopes to some extent, but in general the steep mountain face meets the plain at high angles.

The eastern slope of the mountains is not so precipitous as the western. At altitudes of nearly 6,000 feet the crystalline rocks begin to disappear beneath a corrugated detrital slope of comparatively low gradient, which extends eastward to Big Sandy Wash, a distance of 10 to 15 miles. In this distance the descent is about the same as that attained in the western slope in a much less distance. (See fig. 2.)

At the southern end of the range the mountains cease rather abruptly, giving place to low isolated hills separated by broad passes occupied by the detrital accumulation of the plains. To the east are several comparatively small spurs and detached mountain groups, such as Owens Peak, Peacock Mountains, etc.


Detrital-Sacramento Valley
Grand Wash Trough
Colorado Plateau
Grand Canyon
P
P'
Detrital-Sacramento Valley
Cerbat Mts.
Hualpai Valley
Music Mountain
Q
Q'
Detrital-Sacramento Valley
Hualpai Valley
Temple Bar
Truxton Plateau
Yampai Cliffs
R
R'
Black Mesa
Detrital-Sacramento Valley
Hualpai Mts.
Big Sandy Valley
Aquarius Cliffs
S
S'
The Needles
Mohave Pk
Detrital-Sacramento Valley
Big Sandy Valley
Artillery Peak
T
T'
Detrital-Sacramento Valley
Cactus Plains
Harcuvar Mts.
McMullen Valley
Harquahala Mts.
U
U'
SEDIMENTARY ROCKS
Temple Bar conglomerate and Chemehuevis gravels
Greggs breccia
Paleozoic sediments
IGNEOUS ROCKS
Basalt
Rhyolite and andesite
Granite and gneiss
Horizontal scale in miles
5 0 5 10 15
Vertical scale in feet
10000 0 10000 20000

Rock masses.—The Hualpai Mountains, so far as observed, are composed mainly of coarse-grained granitic rock, becoming gneissoid at the southern end of the range. They are highly mineralized in places, and dikes and quartz veins are numerous. At Cedar, near the summit of the range, mining operations have been successfully carried on for a number of years. The lavas capping the foothills to the west are outlying portions of rhyolites and andesites of the Kingman area (see p. 16), and the small masses in the Peacock Mountains are probably parts of the lavas covering the Truxton Plateau that have been let down to their present position by faulting. The detrital material of the eastern slope is part of the detrital accumulation described under the caption "Big Sandy Valley."

Structure.—The Hualpai Range was apparently formed by the upheaval and tilting eastward of a large crust block, the movement taking place along faults west of the range and at the Cottonwood and Aquarius cliffs. The evidence of block tilting in addition to that given of faulting along the cliffs rests on the steep, scarplike western face of the range, the high angles at which the mountain slope meets the surface of the Sacramento Valley, and the gently inclined débris slope of the eastern face.

AUBREY HILLS.

Location.—South of the Hualpai Mountains and lying between the Sacramento and Big Sandy valleys is a small group known as Aubrey Hills.

Topographic features.—The Aubrey Hills are low, rising but a few hundred feet above the plains on either side. They are separated from the Hualpai Mountains by a low débris-filled pass connecting the Big Sandy and the Sacramento valleys, and from the Buckskin Mountains by Williams Canyon.

Rock masses.—The rock at the northern end of the hills is granitic gneiss. In Williams Canyon occurs similar gneiss overlain by quartzite, argillite, and black metamorphic limestone. From a distance sheets of effusive rock were noted east of the hills, and dark-colored lava, probably basalt, was seen on their western flanks.

BLACK MOUNTAINS.

Location.—The Black Mountains, located in the extreme western part of Arizona, extend from the northern border of the Territory southward to Union Pass.

Topographic features.—The mountains are formed of three more or less distinct groups. The northernmost group, extending from Boulder Canyon southward to Eldorado Pass, a distance of about 15 miles, attains a maximum altitude of about 5,500 feet in Mount Wilson. From this peak the altitude diminishes northward to about

3,000 feet at Boulder Canyon, and southward to about 2,000 feet at Eldorado Pass.

Mount Perkins, 5,500 feet high, is the center of the second group, which consists of a north-south ridge about 30 miles long. The third or southernmost group, about 4,500 feet in maximum altitude, consists of many small irregular hills extending eastward for a considerable distance into the Detrital-Sacramento Valley. The three groups form a continuous range, the apparent separation being due to accumulation of detritus, which fills the old valleys and covers the low-lying passes.

Rock masses.—The core of the Black Mountains consists of granitic rock. In Boulder Canyon coarse-grained crystalline rock occurs, as described by Gilbert,[a] overlain on either side by gneiss. In Pyramid Canyon, farther to the south, and in the hills east of this canyon the rock is granitic gneiss.

The older crystalline rocks of the range are overlain by extensive masses of effusive rock representing several periods of eruption. The oldest of the effusives, the andesite of the Gold Roads region, was not observed in Black and Boulder canyons, but in many places rhyolites and light-colored andesite similar to those overlying the dark-colored andesite of Gold Roads (see p. 27), rest upon the granites and gneisses. These are especially prominent in Black Canyon, where they are many hundreds of feet thick. They were observed near the river at the head of the Cottonwood Valley (section *K*, fig. 6), at the head of Pyramid Canyon, and at many places in the Black Mountains up to an altitude of 3,000 feet or more.

The next younger effusive rocks of the Black Mountains are basalts. They occur in dikes cutting the older rocks and in sheets overlying the rhyolites and younger andesites. North of Union Pass they were outpoured in the Detrital-Sacramento Valley, which had previously been eroded through the rhyolites and younger andesites.

BLACK MESA.

Location.—Black Mesa, about 35 miles long and 5 miles or more in width, is situated between the Colorado and the Sacramento valleys, in the central western part of the area described.

Topographic features.—The mesa is a remnant of a once extensive plateau having a general altitude of about 4,000 feet and a maximum at Mount Nutt of about 5,000 feet. A large part of the plateau has been eroded away and the remaining part deeply dissected by erosion. The bordering cliffs, although deeply incised, form a comparatively regular escarpment at the eastern margin of the mesa, rising 1,000 feet or more above the floor of the Sacramento Valley. The western margin is much more irregular owing to the greater erosion caused by

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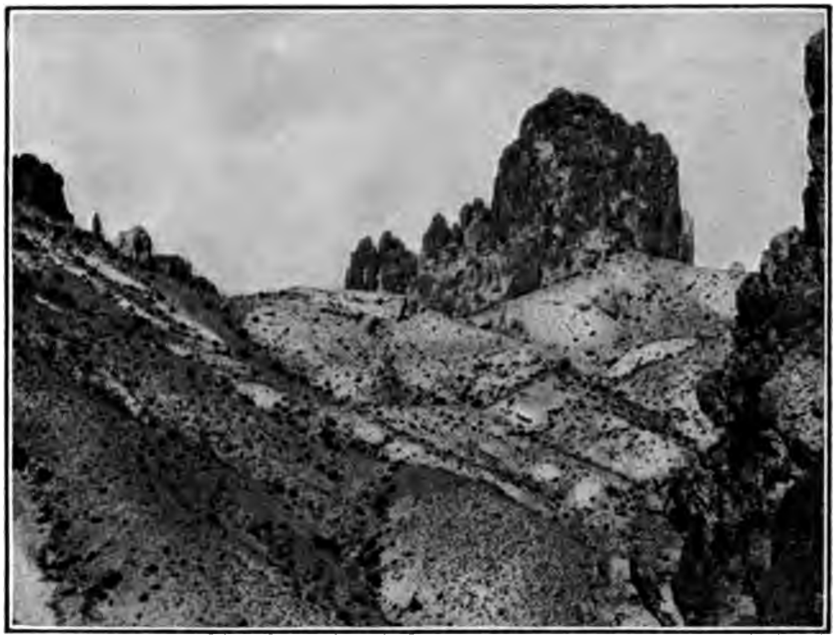
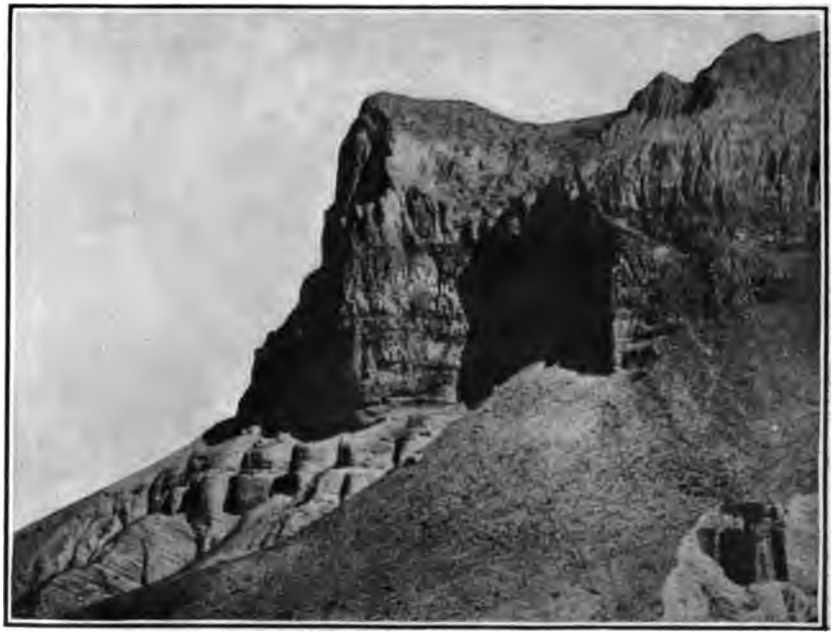
[a] Gilbert, G. K., Final Rept. U. S. Geol. Surv. W. 100th Mer., vol. 3, 1875, pt. 2, p. 35.



A. CASTLE-LIKE EROSIONAL FORMS IN BLACK MESA AT UNION PASS.



B. BASALT-CAPPED GRAVELS IN WILLIAMS CANYON.

the downcutting of Colorado River. On this side are many more or less isolated outlying remnants of erosion, well shown on The Needles special map of the United States Geological Survey, which includes a small part of the southern end of Black Mesa (there called Ute Mountains). The most conspicuous of these outlying masses is Boundary Cone, 3,429 feet high—a sharp pinnacle rising 2,500 feet above the graded detrital slope which stretches from its base westward to Colorado River.

The rock of Black Mesa varies greatly in hardness, and erosion has carved out a great variety of topographic forms. In places where the mesa is composed of moderately uniform layers it is bordered by prominent cliffs of regular outline 1,000 feet or more in height. Where the rock varies in hardness within short distances, as at Union Pass, it is eroded into a great variety of castellated forms. (See Pl. VI, *A*.)

Rock masses.—The granite forming the core of the Black Mountains extends southward underneath Black Mesa, but it is exposed in few places, the mesa to a depth of 2,000 to 3,000 feet being composed mainly of effusive rocks. Granite porphyry was found at the base of Boundary Cone at the western edge of the mesa, and dark-colored andesite at the base of the cliffs at the northeastern extremity; the latter is best exposed in the vicinity of Gold Roads mining camp. The andesite rests upon the granite and is apparently overlain by rhyolite. Wherever observed, however, Black Mesa is composed mainly of rhyolitic tuff, breccia, and flow. The rhyolite is in turn cut by dikes of olivine diabase and overlain to some extent by sheets of basalt.

The granite underlying the rhyolite is penetrated by the well at Yucca and exposed at the base of the hills extending eastward into the Detrital-Sacramento Valley at the northern end of Black Mesa. The thickness of the effusive rock as determined at these points is about 3,000 feet.

MOHAVE MOUNTAINS.

Location.—The Mohave Mountains are located south of Black Mesa, between the Colorado and the Sacramento valleys. They consist of a massive central group, with a spur, known as The Needles, extending westward to Colorado River, and low unnamed hills extending southward to Williams River.

Topographic features.—The central group is subcircular in outline and about 5,000 feet high. It is deeply scored by erosion, and is apparently the remnant of a once much more extensive mountain mass.

The Needles are irregular pinnacles resulting from the erosion of the mass of effusive rock which formerly extended across Colorado River and was later dissected by that river in cutting its present canyon. The unnamed hills north and south of the central mass are remnants of erosion, now separated from the main peak by débris-covered passes.

Rock masses.—With the exception of The Needles, the rocks of the Mohave Mountains, so far as observed, are granite, gneiss, and later intrusives. The crystallines have been greatly fractured and faulted and contain many dikes and veins. The extrusive rock of The Needles overlies the crystalline complex on the eroded flanks of the Mohave Mountains, and is exposed in the canyon down to the river level. The thickness of the effusive rock as measured from the river bed to the summits of The Needles is about 2,000 feet.

HARCUVAR AND HARQUAHALA MOUNTAINS.

Location.—The Harcuvar and Harquahala mountains are located in the southern part of the area described, and extend from the eastern border of this area about 50 miles in a general southwesterly direction. They resemble each other in many ways and may be described together.

Topographic features.—The axes of these mountains lie in a direction practically at right angles to those of the other ranges of the region. Next to the Hualpai Mountains they are the loftiest in central western Arizona.

Both ranges are narrow, with precipitous slopes rising abruptly to altitudes of several thousand feet above the graded plain which surrounds them. The main range of the Harcuvar Mountains is broken at Cunningham Pass, and at either end the ranges break up into isolated hills. At the west end of these mountains a group known as the Granite Wash Hills exhibits a tendency to return to the north-south trend characteristic of the other ranges of western Arizona.

Rock masses.—The rocks were observed only in Cunningham Pass in the Harcuvar Mountains and near Harrisburg in the Harquahala Mountains, where they consist of a crystalline complex underlying and to some extent including masses of quartzite, argillite, and metamorphic limestone. A few miles south of Harrisburg, where these sediments were examined most closely, the strata stand nearly vertical.

BUCKSKIN MOUNTAINS.

Location.—The Buckskin Mountains, lying immediately south of Williams River, are virtually the southward continuation of the Aubrey Hills, being separated from them only by the narrow gorge cut by Williams River.

Topographic features.—The Buckskin Mountains are lofty at their eastern extremity, with a precipitous slope facing southward. The group is greatly eroded, the peaks being separated by comparatively low passes. The western part is composed of irregular hills formed by the dissection of a plateau of igneous rock, the general surface of which has an altitude of about 2,400 feet. The topographic features of the basalt-covered plateau near the mouth of Williams River are especially conspicuous (Pl. VI, *B*). The basalt of the surface is very resistant, and the underlying sand and gravel (see p. 54) is easily eroded, resulting in the formation of precipitous cliffs nearly 2,000 feet high.

Rock masses.—The rocks of the Buckskin Mountains consist of biotite granite, granitic gneiss and schist, metamorphic sediments, and effusive rocks. The gneisses and schists are conspicuously exposed in Williams Canyon, where they are horizontally laminated and fissile, suggesting the name Banded Canyon, by which Williams Canyon is locally known.

The crystalline rocks are overlain by quartzites, slates, and black metamorphic limestones. These are faulted and intersected by intrusive rocks, and contain deposits of copper and iron ore. A bed of hematite about 150 feet thick was observed near Planet.

PALOMAS AND DOME ROCK RANGES.

Location.—The Palomas and Dome Rock Mountains, in the southwestern part of the region, were not visited by the writer. Their form and location are taken from the railway-location map made by the Santa Fe engineers in locating the Arizona and California Railroad, furnished for this bulletin by the chief engineer, W. A. Drake. Little is definitely known of their topographic features or rock masses.

GEOGRAPHIC AND GEOLOGIC DETAILS OF VALLEYS.

COLORADO VALLEY.

GENERAL STATEMENT.

Colorado River was traversed by boat from the mouth of Grand Canyon southward to Yuma, a distance of about 325 miles. Throughout this course the rocks in which the valley is eroded are well exposed and geologic features of great variety are well exhibited. For convenience of description the valley is divided into sections, the important features being taken up in order from the mouth of the Grand Canyon downstream. Several diagrammatic sections across the valley are included with the descriptions in order to illustrate relations not adequately shown in the more generalized sections on Pl. V.

In the published accounts of Major Powell's explorations of the Colorado little is said of the river west of the mouth of Grand Canyon.

The current is swift as far south as the mouth of Black Canyon, the fall being about 400 feet, or about 5 feet to the mile. There are several rapids of considerable size, formed by bowlders washed into the river from tributary canyons. The largest of these are: (a) Near Pierce Ferry in the Grand Wash Trough, caused by bowlders from the Greggs breccia entering from the south; (b) at the mouth of Grand Wash, caused by bowlders from this wash; (c) 3 miles east of the Nevada-Arizona boundary, caused by bowlders from a small wash entering from the north; (d) Red Granite Rapids, 3 miles west of the Nevada-Arizona boundary, at which point there is a long bowlder strainer[a] on the Arizona side which deflects the river sharply against the red granite on the Nevada side; (e) Hualpai Rapids, formed by the bowlders from Hualpai Wash; (f) Reverse Rapids, in Boulder Canyon; (g) Roaring Rapids, in Black Canyon.

MOUTH OF GRAND CANYON.

Colorado River emerges from the Plateau region about 7 miles east of the Nevada-Arizona boundary. The Grand Wash Cliffs, which form the western border of the plateau, rise to an altitude of about 4,500 feet, or 3,500 feet above the river. A few miles north of the rim of the canyon Shiwitz Plateau rises to an altitude of about 6,300 feet.

Grand Canyon is very narrow at its mouth (Pl. VII, *B*), and nearly perpendicular walls of Redwall limestone, sandstone and shale of the Tonto formation, and granite (see pp. 14–15) rise from the water's edge on either side. Springs emerge from these formations in many places and deposit carbonate of lime. The lower portion of the canyon walls is covered in many places with calcareous tufa and pendants of travertine. In some places the travertine projects irregularly, inclosing picturesque cavern-like chambers; in other places it forms basins built out into the river.

Massive beds of travertine were observed on both sides of the canyon at an elevation of 500 feet or more above the river. These may have been built out from the canyon sides by springs and later partly eroded away, but their horizontal bedding and location on opposite sides of the canyon at about the same altitude (see section *A*, fig. 3) indicate that they are probably remnants of a mass which formerly filled the canyon to a depth of several hundred feet. They are probably part of an extensive travertine formation having its greatest development near Hualpai Wash.

GRAND WASH TROUGH.

The Grand Wash Trough, lying between the Grand Wash Cliffs and Iceberg Canyon, is a depression formed by faulting and by the tilting

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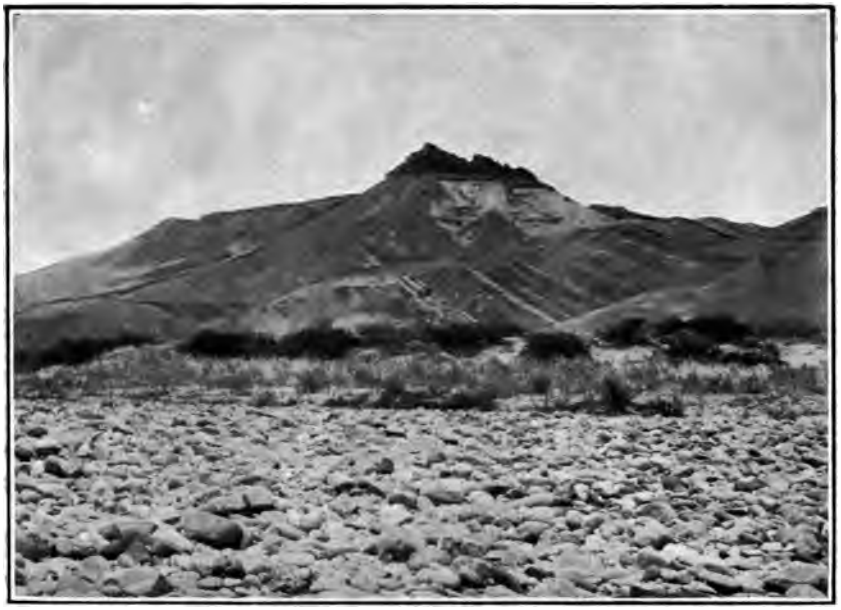
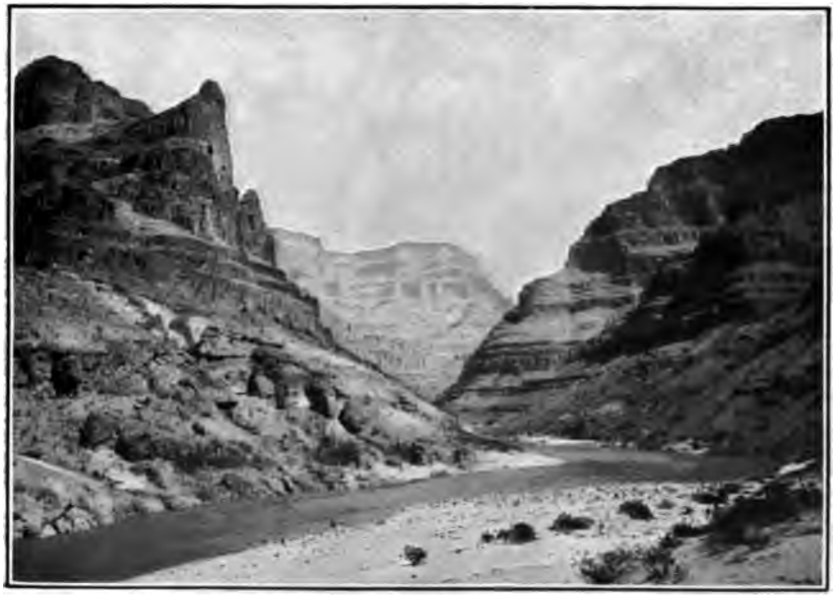
[a] "Strainer" is a term used locally to designate an accumulation of bowlders forming a porous dam in the river, through which the water finds its way as through a strainer.



A. NORTH WALL OF CANYON IN GRAND WASH TROUGH.



B. MOUTH OF GRAND CANYON.

of a large crust block. It derives its name from Grand Wash, which here enters the Colorado from the north. Its western limb consists of strata of the tilted block, and its eastern limb is the fault scarp of the Grand Wash Cliffs.

Not only are all the rock formations composing the Grand Wash Cliffs found in the tilted block in Iceberg Canyon, but strata younger than those in the cliffs are also present and pass beneath the river level with an eastward dip of 60° to 80°. Making no allowance for dip and considering only the altitude of corresponding strata in the walls of Grand Canyon and in Iceberg Canyon, the downthrow at the Grand Wash fault is about 5,000 feet. The strata of the block pass beneath the river level several miles west of the fault line. If the downthrow be computed from the dip of the strata and the distance from the fault line at which they pass beneath the river, the displacement at Grand Wash fault appears to be several times greater than the 5,000 feet in evidence at the surface.

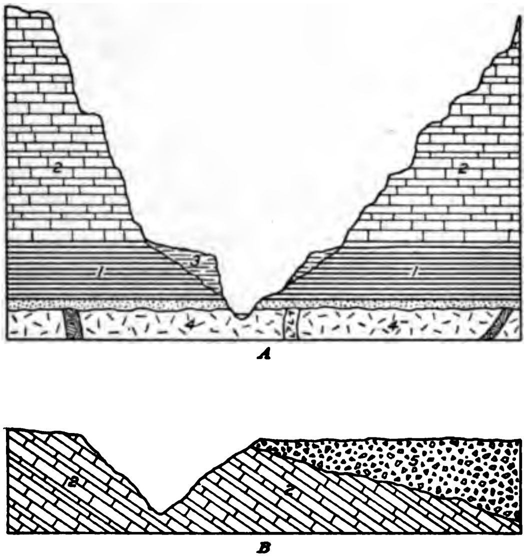


Fig. 3.—Diagrammatic sections across Colorado River. *A*, At mouth of Grand Canyon; *B*, in Iceberg Canyon. 1, Cambrian; 2, Redwall limestone; 3, travertine; 4, granite; 5, Greggs breccia.

The magnitude of the Grand Wash fault has long been recognized. Gilbert[a] states that the most profound dislocation of the plateau region has occurred at this fault, and Dutton,[b] in describing it, writes that "the plateau had its origin in a great fault along the crest of which the country east of it has been hoisted several thousand feet above the country on the west." Again he writes "It [the Grand Wash Cliffs] is a feature of the highest importance, since it is the boundary not only of the Grand Canyon district, but of the Plateau province itself. It drops the country on the west about 6,000 feet at a maximum." Huntington and Goldthwaite[c] have recently shown that the fault is traceable northward to the vicinity of Toquerville, Utah, a distance of about 80 miles, where it joins the Hurricane fault. The present writer traced it southward into the Hualpai Valley, where it apparently forks, the western branch reappearing west of the Hualpai Mountains and the eastern one following the cliffs.

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[a] Gilbert, G. K., Final Repts. U. S. Geog. Survey W. 100th Mer., 1873, pt. 1, p. 54.

[b] Dutton, C. E., Tertiary history of the Grand Canyon district: Mon. U. S. Geol. Survey, vol. 2, 1882, pp. 12, 19.

[c] Huntington, Ellsworth, and Goldthwaite, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 42, 1904.

The Grand Wash Trough is filled with Greggs breccia to an altitude of about 2,500 feet, or 1,500 feet above the river. Where the breccia was examined most carefully, in the bluffs south of the river about 4 miles east of Greggs Ferry, it was found to be composed of unassorted and poorly stratified débris consisting of angular rock fragments, principally granite, the largest having a diameter of 10 feet or more. Toward the top the fragments were cemented by carbonate of lime into a very resistant mass, forming the cap rock of certain conspicuous cliffs east of Greggs Ferry. The upper 100 feet or more of this capping stratum is travertine and is nearly devoid of rock fragments. Farther south the surface consists of the truncated edges of the upturned limestone block. (See section *P-P'*, Pl. V.)

The breccia of the Grand Wash Trough has been much more eroded north of the river than south of it. The breccia was not examined far from the river, but, judging from the size and character of the bowlders brought down by the washes, it is probable that the material in the midst of the trough does not differ greatly from that described from the cliffs at its western edge near Greggs Ferry.

The Temple Bar conglomerate also occurs in the Grand Wash Trough, appearing in many places at altitudes several hundred feet higher than the river, in depressions previously eroded in the older rocks. It is composed of sand and waterworn pebbles of quartzite, limestone, marble, etc., not distinguishable at the present time from the gravels derived from Grand Canyon. These are in places cemented by carbonate of lime into very resistant masses, forming nearly perpendicular cliffs 500 feet high. The travertine deposits just described within the canyon were probably formed at the same time.

The Temple Bar conglomerate of the Grand Wash Trough contains a thick sheet of basalt. The lava appears in the face of a cliff in Iceberg Canyon in the midst of the conglomerate, and in the Grand Wash Trough as a columnar sheet overlying the conglomerate. The relation of the Temple Bar conglomerate to the underlying sedimentary formations of the tilted block and to the overlying sheet of basalt is shown in Pl. VII, *A*.

The Greggs breccia, where exposed near the river within the Grand Wash Trough, is roughly stratified, and the strata are tilted eastward, the maximum dip observed being about 30°. The Temple Bar conglomerate is also locally disturbed, dips of 10° eastward being observed in places. At the base of the Grand Wash Cliffs the detrital material ends abruptly against the sedimentaries at the fault line, and is locally disturbed by movements apparently of recent date.

The somewhat complicated relations in the Grand Wash Trough may perhaps be made clearer by a brief statement of the events in the order of their occurrence. The formation of the Grand Wash fault and the tilting of the crust block were followed by a long period of erosion and deposition, which filled the trough with débris and planed off the upturned edge of the block, bringing the surface to a graded condition. The Colorado Plateau to the east was apparently at the level of this graded plain. Then followed a second period of faulting, in which great displacements occurred at the Grand Wash fault and minor displacements at several smaller faults to the west, accompanied by further tilting of the crust block and the elevation of the Colorado Plateau. This uplift of the plateau resulted in the inauguration of Grand Canyon, the river cutting directly across the Grand Wash Trough. The erosion proceeded until the canyon was cut to a depth practically the same as that it has at the present time. This was followed by deposition of gravels and of the Temple Bar conglomerate, and by eruptions of basalt, after which occurred renewed faulting and tilting of the limestone block, the Greggs breccia, and the Temple Bar conglomerate. Erosion again became active, and a second time the canyon was eroded to a depth greater than that it now has.

Later events, which are important farther downstream, are not conspicuously recorded in the Grand Wash Trough.

HUALPAI WASH.

Hualpai Wash enters Colorado River from the south and occupies a structural depression between the western edge of the limestone block on the east and the crystalline rocks of the White Hills on the west. This trough extends northward across the river and is there filled with gravel deposits, but their relation to other formations was not determined.

In Hualpai Wash a limestone several hundred feet thick occurs. In some places it is a massive, pink, compact rock resembling the Redwall limestone of the canyon section. Unlike that limestone, however, its character varies within short distances from a compact rock to a comparatively soft earthy substance, weathering with rough cavernous surface. In Hualpai Wash it rests directly upon an irregular surface of granite. In other places it abuts rather abruptly against previously existing granite cliffs, and contains fragments of the granite embedded within it. In still other places it apparently rests upon beds of sand and clay, although this observation was not satisfactory.

The material is similar in character to the travertine capping Greggs breccia (section *C*, fig. 4), and to that occurring in beds 500 feet or more in thickness in the mouth of Grand Canyon (section *A*, fig. 3). It is apparently a travertine deposit belonging either to the Greggs deposits, let down to its present position by faulting (section *D*, fig. 4) or to the Temple Bar deposits, both of which are known to contain large beds of travertine. Its relation to the sedimentary rocks and to the underlying granite of the tilted block to the east is shown in the sketch sections in fig. 4.

Within the canyon, resting unconformably upon Temple Bar conglomerate and the older formations at various points on either side up to an altitude of 150 to 200 feet above the water level, occur unconsolidated gravels. They are not conspicuous east of Iceberg Canyon, although some gravel beds in the Grand Wash Trough above high-water level may have been formed at the same time. Farther downstream they are conspicuously developed and are there known as the Chemehuevis gravel.

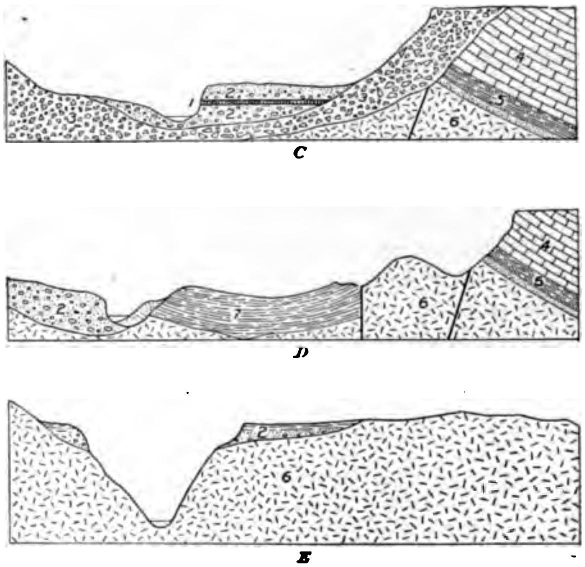
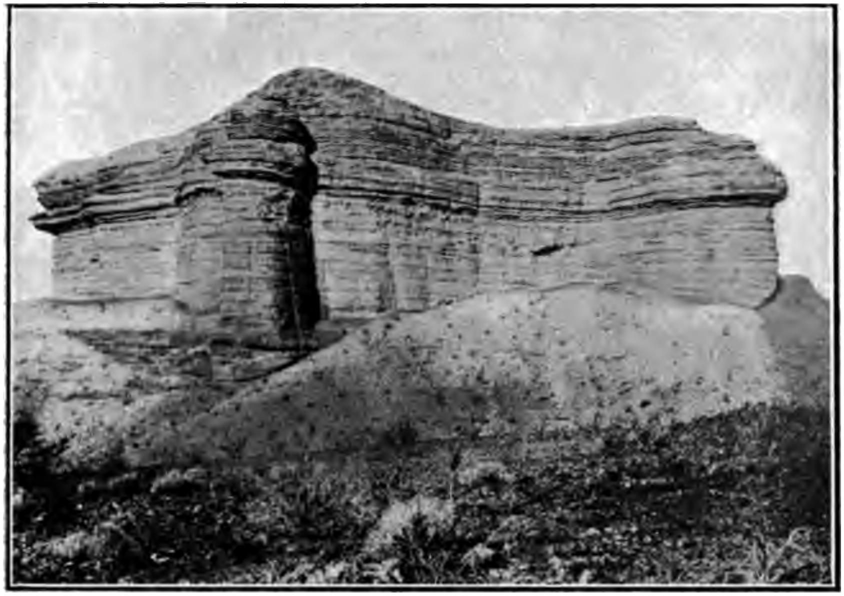


FIG. 4.—Diagrammatic sections across Colorado River. *C*, 4 miles east of Greggs Ferry; *D*, near Hualpai Wash; *E*, in Virgin Canyon. 1, Basalt; 2, Temple Bar conglomerate; 3, Greggs breccia; 4, Redwall limestone; 5, Cambrian; 6, granite; 7, travertine.

VIRGIN CANYON.

At the mouth of Hualpai Wash Colorado River enters a narrow rock gorge cut in the crystalline rocks of the Virgin Range. The canyon is about 5 miles long and from 1,000 to 1,500 feet deep, with walls rising steeply from the water's edge on either side.

High in the sides of the canyon walls occur remnants of light-colored, horizontally bedded material. (See section *E*, fig. 4.) These were not examined closely, but from a distance they have the same general appearance as the Temple Bar conglomerate characteristically developed at the same altitude a few miles farther west.



A TEMPLE BAR CONGLOMERATE RESTING UPON OLDER BRECCIA, NEAR TEMPLE BAR.

B. ENTRANCE TO BLACK CANYON

TEMPLE BAR.

Virgin Canyon widens westward as the river emerges from the crystalline rocks and enters the detrital beds. At Temple Bar the sand and gravel filling the Detrital Valley is exposed in vertical cliffs several hundred feet high. At the base of the cliffs is a coarse breccia exposed through a thickness of about 300 feet and composed principally of fragments of a rhyolite flow breccia cemented into a resistant mass. The cementing material is mainly carbonate of lime, but in some places it is silica and in other places oxide of iron. Springs issuing from this breccia are strongly charged with common salt and alkali, which gather as white incrustations about the springs.

Resting unconformably upon this breccia and abutting against it, as illustrated in section *F*, fig. 5, occurs the characteristic Temple Bar conglomerate. The conglomerate consists of well-stratified sand and gravel (see Pl. VIII, *A*), and, although poorly consolidated, forms perpendicular cliffs hundreds of feet in height. Pl. II shows this conglomerate in one of its most characteristic exposures, where the cliffs rise abruptly from the water's edge to a height of 815 feet. A large number of equally conspicuous sand and gravel cliffs and monuments occur in the vicinity of Temple Bar, extending from the river level to altitudes of 2,000 to 2,500 feet.

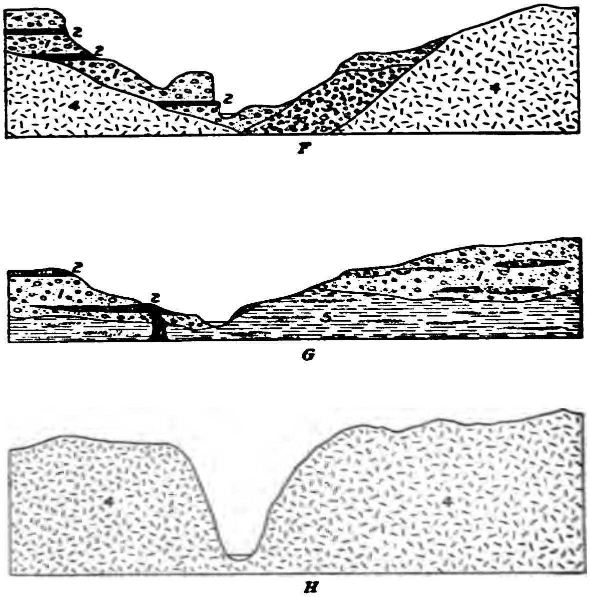


FIG. 5.—Diagrammatic sections across Colorado River. *F*, At Temple Bar; *G*, at Virgin River; *H*, in Boulder Canyon. 1, Temple Bar conglomerate; 2, basalt; 3, Greggs breccia; 4, granite; 5, salt and gypsum beds.

Sheets of basalt occur at several horizons of the conglomerate. A shelf about 200 feet from the base (see Pl. II) is formed by one of these sheets of basalt, and other sheets occur at higher horizons (section *F*, fig. 5). South of the river a basalt sheet resting on top of the gravel beds may be younger than those included in them, or may be one of the included sheets exposed by erosion.

The composition, stratigraphic relations, and general appearance of the older or cemented breccia suggest that it is probably a time equivalent of the Greggs breccia. The gravels above it form the Temple Bar conglomerate, which derives its name from this locality. The younger or Chemehuevis gravel is also present at Temple Bar, but is not conspicuous.

VIRGIN VALLEY.

Between Temple Bar and Boulder Canyon, a distance of about 12 miles, Colorado River crosses the old débris-filled valley which to the south of the Colorado is known as the Detrital-Sacramento Valley and to the north as the valley of the Virgin.

The filling of this old valley is apparently composed of two distinct formations, but their relation was not satisfactorily determined. The older one consists of alternating layers of sand and clay, and contains extensive beds of gypsum. Rock salt occurs in the Virgin Valley a few miles north of the Colorado, in beds similar to those containing the gypsum. These salt beds apparently lie beneath the gypsum, as shown by the salt well near the mouth of Virgin River, described by Gilbert.[a] The salt well is a crater-like depression about 300 feet across and 65 feet deep, situated in the midst of a level gravel plain. It is not connected with any surface drainage, and is evidently formed by a local caving of the surface probably due to the removal by solution of underlying beds of salt. It is filled with salt water to a depth of 15 to 20 feet.

The gypsum and gypsiferous clays are conspicuously exposed along the river, where they are deeply dissected over a large area locally known as the badlands of the Virgin. The presence of gypsum and salt indicates that this formation is not a part of the Temple Bar conglomerate, which overlies it with apparent unconformity (section *G*, fig. 5) and which does not contain gypsum or salt in its typical exposures so far as observed. The relation of the gypsiferous shales to the underlying rocks and to the overlying conglomerates was not satisfactorily determined. The stratigraphic position, however, suggests that this formation may be a time equivalent of the Greggs breccia.

BOULDER CANYON.

Boulder Canyon is a sharp gorge cut by Colorado River through the Black Mountain Range. It is about 5 miles long and 2,000 feet or more in depth, the walls rising steeply from the water's edge. The rocks exposed in the canyon are syenite, gneiss, rhyolite, and basalt. The basalts and their associated gravel deposits near the entrance to the canyon are faulted and tilted to some extent, and faults and open fissures occur in the canyon walls.

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[a] *Gilbert, G. K., Final* Rept. U. S. Geol. Survey W. 100th Mer., vol. 3, 1875, pt. 1, pp. 109-110.

Boulder Canyon is apparently younger than Virgin Canyon. The walls are but slightly eroded by lateral washes, although the open fissures and shattered condition of the rock in many places are favorable to the development of such; none were observed containing beds of the Temple Bar conglomerate, as is the case in Virgin Canyon.

LAS VEGAS WASH.

West of Boulder Canyon, and extending southward to the head of Black Canyon, the river flows through a débris-filled basin in which Colville and Las Vegas washes join the river from the north and west. Detrital beds resembling the Temple Bar conglomerate and containing sheets of lava are capped by a thick lava sheet in Fortification Hill at an altitude of 3,500 feet, or nearly 2,500 feet above the river (section *I*, fig. 6). The gravels are well stratified and are faulted and tilted in places.

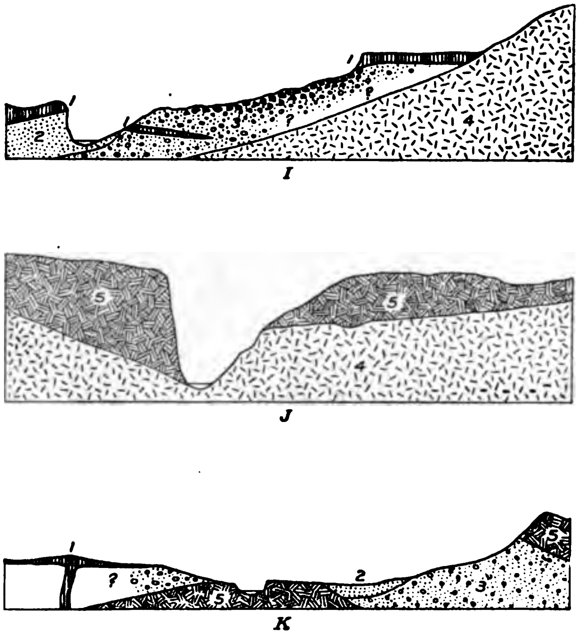


FIG. 6.—Diagrammatic sections across Colorado River. *I*, Near Las Vegas Wash; *J*, in Black Canyon; *K*, at Little Round Island. 1, Basalt; 2, Chemehuevis gravel; 3, Temple Bar conglomerate; 4, granite; 5, andesite and rhyolite.

BLACK CANYON.

A few miles south of Fortification Hill the river leaves the detrital basin and enters Black Canyon, a deep, narrow rock gorge about 18 miles long. The walls rise steeply from the water's edge (see Pl. VIII, *B*), and are composed to some extent of coarse crystalline rock, but mainly of massive rhyolite (section *J*, fig. 6). Black Canyon is very similar to Boulder Canyon in its general youthful appearance and in the absence of notable tributary washes and remnants of gravel beds.

COTTONWOOD VALLEY.

A few miles north of Eldorado Ferry the river emerges abruptly from Black Canyon into a broad open basin, the central part of which is known as the Cottonwood Valley. The basin is about 30 miles long and extends laterally from the Dead Mountains on the west to the Black Mountain Range on the east. At the northern

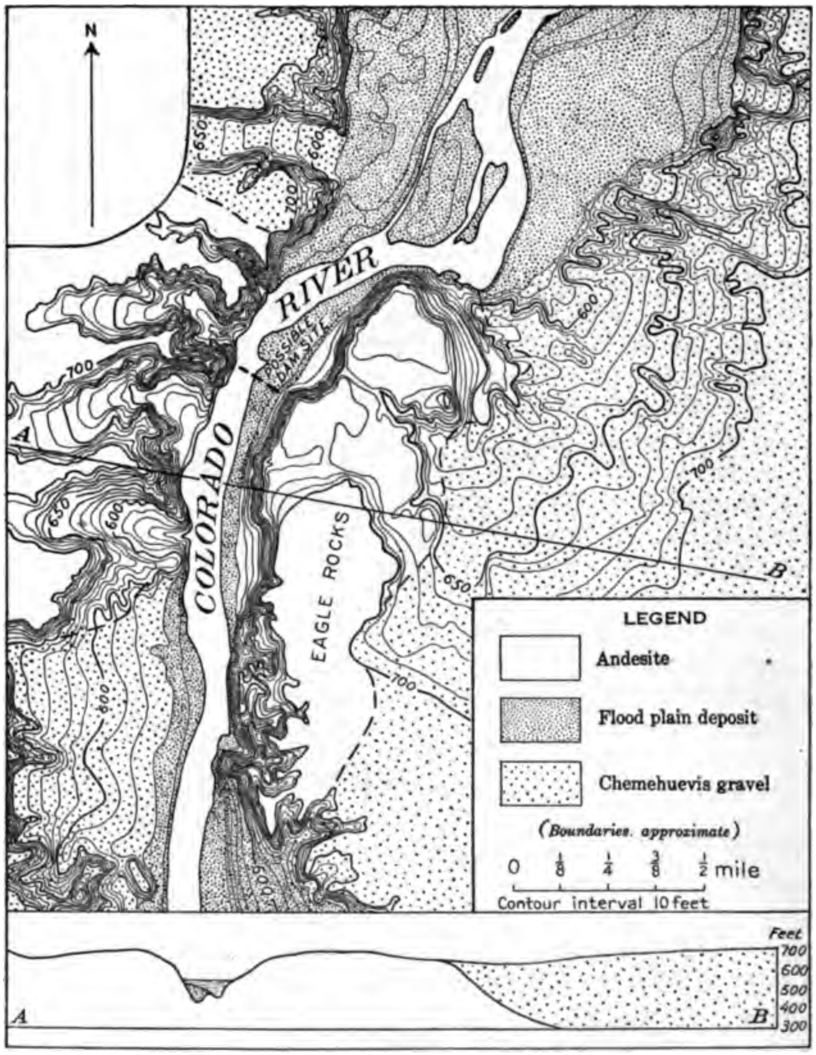
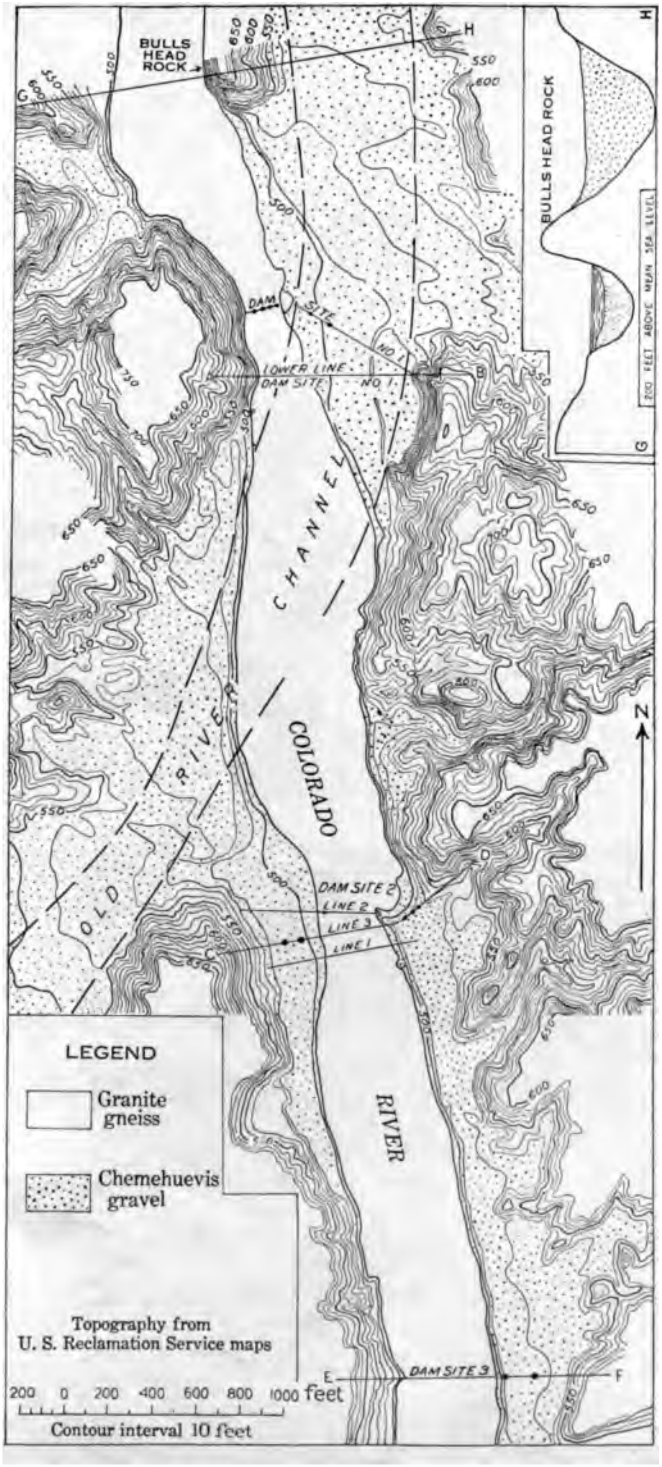


FIG. 7.—Map of a part of the Colorado Valley at the northern end of the Cottonwood Valley, showing an old gravel-filled channel at the right and the rock channel of the river at the left.

end of the basin gypsum-bearing beds similar to those near the mouth of the Virgin occur with an observed thickness of several hundred feet.



MAP AND SECTION AT SOUTH END OF PYRAMID CANYON, COLORADO RIVER.

Near Round Island partly consolidated gravel beds similar in general appearance to the Temple Bar conglomerate and intersected by basalt dikes (see section *K*, fig. 6) occur above andesitic lavas. The gravels are well stratified, tilted steeply to the east, and extensively eroded. Horizontally bedded Chemehuevis gravel lies in depressions eroded in older upturned beds which in turn are younger than the andesites. For these reasons the older gravels are provisionally correlated with the Temple Bar conglomerate.

The Cottonwood Valley is the northernmost of a series of large basins which extend thence southward to the Gulf of California. The flood plain in the center of the valley is terminated laterally by bluffs of the Chemehuevis gravel. Between these bluffs and the mountains on either side are long corrugated slopes covered with angular rock débris or wash from the highlands. The slopes in the Mohave Valley were examined with more care than elsewhere, and are described in a following section. (See pp. 41–42.)

At Eagle Rock, near the southern end of Round Island, the river leaves the flood plain and flows through a narrow rock gorge about a mile long and 150 feet deep. The rock is andesite, and its relation to the gravel formations is shown in fig. 7. The gravel-filled channel to the east connects the Round Island Valley with the Cottonwood Valley proper. In other words, Colorado River, during one of its periods of canyon cutting, described under "Geologic history" (pp. 62–67), failed to reexcavate its old gravel-filled channel at Eagle Rock and cut a new channel in the rock west of the old one.

PYRAMID CANYON.

South of the Cottonwood Valley the granite and gneiss of the bordering mountains extend across the valley of the Colorado, and through these rocks the river has cut a canyon about 300 feet deep and 8 miles long. This is known as Pyramid Canyon, the name being derived from a pyramid-shaped rock near the northern end. East of the canyon, and separated from it by a narrow rock ridge (see Pl. IX), is an old channel filled with sand and gravel—Chemehuevis gravel—remnants of which occur 400 feet or more above the river, overlying and abutting against the granite and gneiss, as shown in Pl. III, *B*.

One of the proposed dam sites of the Reclamation Service is located at the southern end of Pyramid Canyon, near Bulls Head rock, the southern extremity of the rock ridge. On account of the investigations of the Reclamation Service in this vicinity much exact information is available. On this account the Bulls Head region is perhaps the best locality for the description and illustration of the late physiographic history of Colorado River. Unfortunately the detailed maps do not extend far enough northward to show to advantage the relation of the new rock channel to the old gravel-filled valley, but its southern end is shown in Pl. IX, and its relations are indicated in fig. 8. In Pl. X, *A*, a view of Bulls Head rock is presented, showing the river channel to the left and the gravel-filled valley to the right, as seen from the south. At intervals for several miles north of Bulls Head rock the ridge between the old and new channel is cut through by tributary washes, exposing such sections of the Chemehuevis gravel as that shown in Pl. III, *B*.

The old course was not so satisfactorily traced to the south. As shown on the map, it apparently crossed the present course of the river at a point where the gravels fill a depression similar to that at the north, and connected with the extensive gravel deposits of the Mohave Valley to the south.

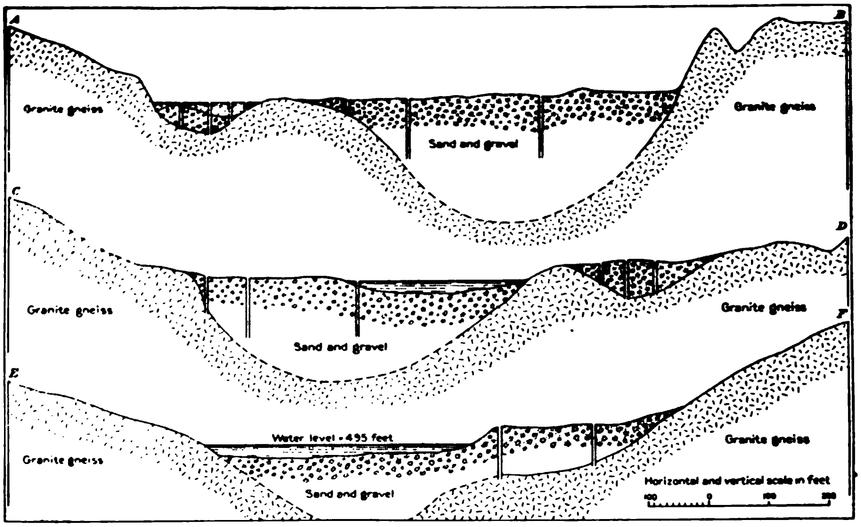
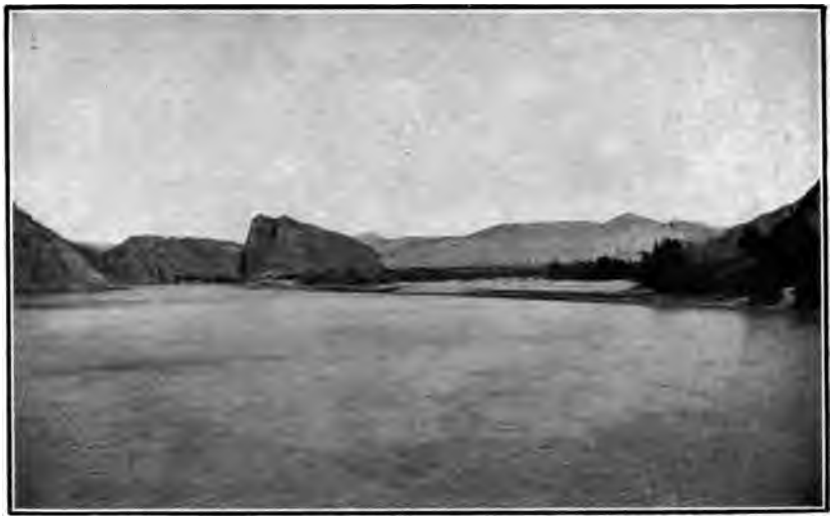


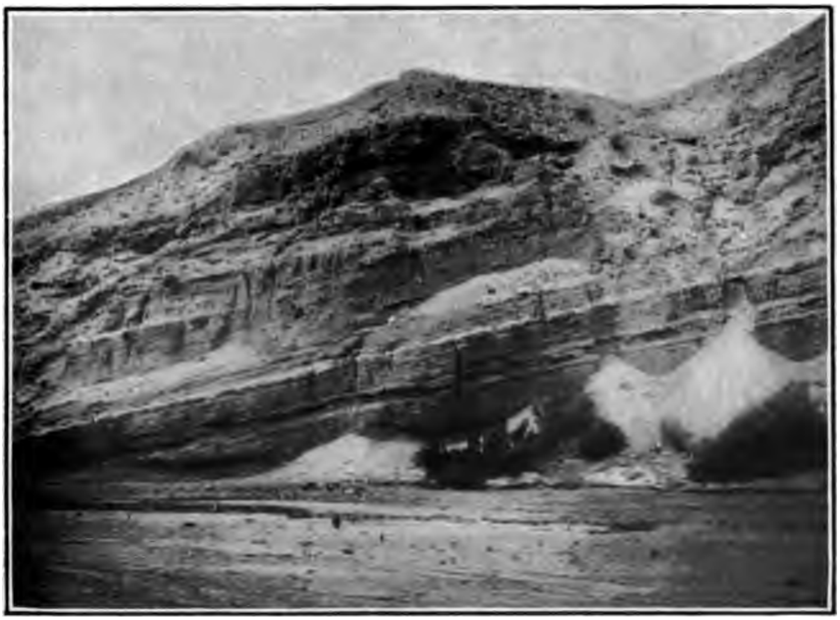
FIG. 8.—Profiles across Colorado River at the southern end of Pyramid Canyon, constructed from boring records. (For location see Pl. IX.)

Although the river occupies a narrow rock channel in Pyramid Canyon, it does not flow upon a rock bed, as might be expected. Borings were made for the Reclamation Service in three localities across the river (see Pl. IX), and the gravel filling was found to be more than 100 feet deep. The probable profiles, as constructed from the boring records, are shown in fig. 8.

No distinction can be drawn with certainty between the old and new channels at the places where the borings were made. At the northernmost locality (section *A-B*, fig. 8) the channel at the left now occupied by the river, in which the gravels are about 50 feet deep, is apparently the new one, and that at the right, more than 100 feet



A. COLORADO RIVER AND GRAVEL-FILLED VALLEY AT BULLS HEAD ROCK.



B. TILTED GRAVELS IN SACRAMENTO WASH.

deep, the old one; but in the absence of soundings within the canyon north of Bulls Head, the depth of the new channel remains in doubt. Borings 100 feet deep in the older channel do not penetrate through the gravels.

A brief statement of the physiographic history of the river, as here recorded, may give a clearer understanding of the phenomena described. The river at some former time occupied the old course to the east (Pl. IX) and eroded its channel to a depth considerably below the present river level. Later the Colorado deposited the Chemehuevis gravel, filling its valley with sand and gravel to a level several hundred feet above the present bed. When the river again began to erode, it reexcavated the old valley throughout the greater part of its course, but in Pyramid Canyon, at Eagle Rock (described in the previous section), and at other places farther south to be described in following sections, it left its old course and cut rock gorges at one side.

MOHAVE VALLEY.

The Mohave Valley is a large basin extending from Bulls Head southward to The Needles, a distance of about 35 miles. The center of the basin is occupied by a broad flood plain having an area of about 50,000 acres. This is bordered on either side by terraced gravel bluffs, from which long, graded, alluvial slopes extend to the bordering mountains, joining the slopes at altitudes of 2,500 to 3,000 feet.

The rock masses in the Mohave Valley were examined principally east of the river. The rocks of Black Mesa to the east are mainly andesite and rhyolite, resting upon granitic gneiss. Overlying these older rocks occurs a formation of partly consolidated sand and gravel, which in composition and general appearance resembles the Temple Bar conglomerate. It is exposed in steep cliffs in the washes of the alluvial slope, and the strata are generally nearly horizontal. In some places, however, the layers are faulted and tilted (see Pl. X, *B*). These stratified sands and gravels are covered with coarse rock débris, due partly to wash from the hills and partly to surface concentration of the coarser material of the conglomerate.

Resting upon this formation and occupying spaces eroded in it is the Chemehuevis gravel, forming conspicuous terraces, three of which are prominent and traceable continuously for considerable distances; in some places five are distinguishable. The lowest is about 50 feet above the river, and is represented by the broad shelf upon which old Fort Mohave stands; the second is about 100 feet higher, and the others occur at intervals of 50 to 100 feet.

The Chemehuevis gravel varies considerably in character from place to place from beds of large, well-rounded pebbles to those of fine sand and clay. At the northern end of the Mohave Valley, near Bulls Head, there are two distinct divisions of the gravel. (See Pl. III, *B*.) The lower division consists mainly of well-stratified and firmly packed sand and silt; the upper of stratified but very loose sand and gravel. The two divisions appear to be perfectly conformable, and the difference in character is probably due to some change in the river, such as an increase in its carrying power, enabling it to bear the finer material away and deposit only the coarser material; or to a change in course, bringing the gravel-bearing current over what had formerly been a flood plain.

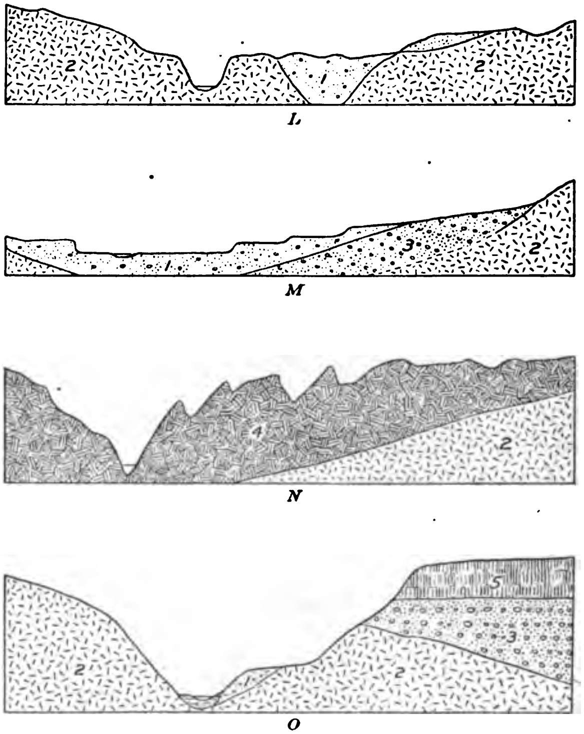


FIG. 9.—Diagrammatic sections across Colorado River. *L*, Pyramid Canyon; *M*, in the Mohave Valley; *N*, in the Needles Mountains; *O*, at the mouth of Williams River. 1, Chemehuevis gravel; 2, granite; 3, Temple Bar conglomerate; 4, eruptive; 5, basalt.

The gravels in the old channel east of Pyramid Canyon were examined with considerable care and found to consist of limestone, marble, sandstone, and metamorphic and igneous rocks of great variety. Many of the limestone pebbles have beautifully etched surfaces, which Gilbert[a] describes as "carved with a network of vermicular grooves into a most beautiful arabesque design." These etched pebbles were observed in the Chemehuevis gravel throughout the region described.

THE NEEDLES.

South of the Mohave Valley occurs a mass of eruptive rock resting on the flanks of the Mohave Mountains (section *N*, fig. 9), and characterized by sharp pinnacles of erosion, from which the group has been called The Needles. Mohave Canyon, about 8 miles long, has been cut in this eruptive mass to a depth of about 2,000 feet. In general the rock walls rise abruptly from the water's edge, but in some of the more open spaces sand and gravel of the Chemehuevis formation occur to a considerable height above the river.

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[a] Gilbert, G. K., U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, pt. 1, pl. 9 and p. 83.

At Big Bend, 4 miles south of Mellen, the river leaves a comparatively open portion of the canyon and turns abruptly to the west into a narrow rock gorge having an old gravel-filled channel, which continues southward in the normal direction of the river (fig. 10).

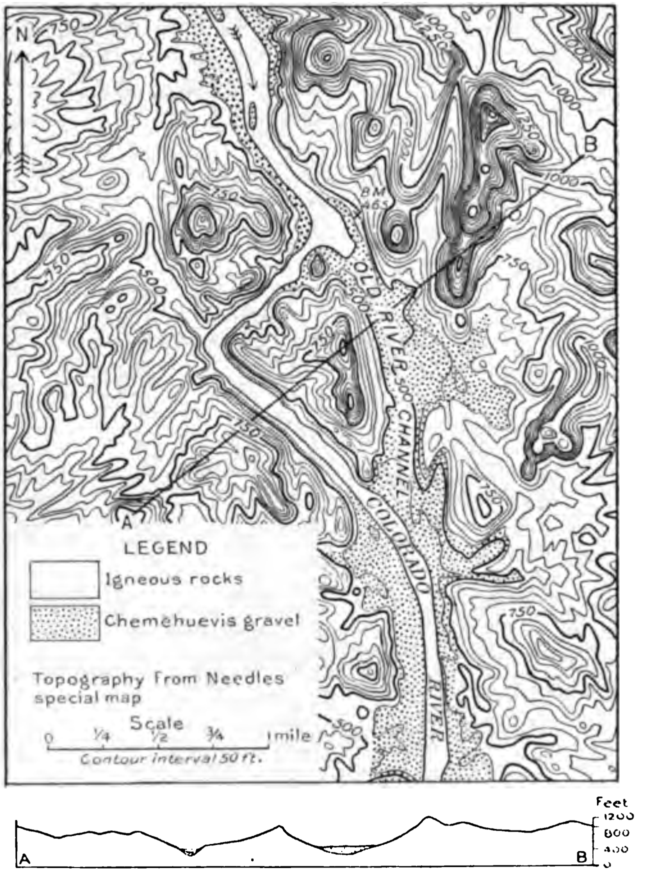

FIG. 10.—Map of Great Bend in Mohave Canyon, showing relation of an old débris-filled channel to the present course of Colorado River.

The phenomena here are similar to those just described from Pyramid Canyon, except that the new course is shorter and the gravel filling of the old one has been more nearly eroded away than in Pyramid Canyon.

CHEMEHUEVIS VALLEY.

The Chemehuevis Valley extends from The Needles to the mouth of Williams River, a distance of about 25 miles, and is narrower than the other basins along the course of the river. The Chemehuevis gravel, which derives its name from this valley, occurs here in characteristic development, lying unconformably upon older and partly consolidated gravels. The older gravels are horizontally bedded in some places but in others are faulted and highly inclined.

The relation of the Chemehuevis gravel to the older conglomerate was noted at several points along the river. In some places the older gravels are undisturbed beneath the Chemehuevis, the two being separated by an unconformity of erosion (section *A*, fig. 11). In other places the older gravels are upturned, eroded, and overlain by horizontally stratified Chemehuevis gravel (section *B*, fig. 11). In still other places the older gravels are tilted, intersected by lava, eroded, and overlain by the Chemehuevis gravel (section *C*, fig. 11).

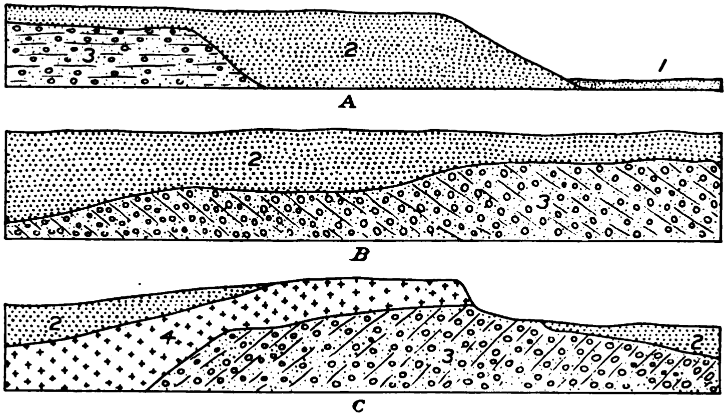

FIG. 11.—Relations of gravel formations to each other and to igneous rock in the Chemehuevis Valley. *A*, The three gravel formations horizontally bedded but separated by unconformities of erosion; *B*, the older conglomerate tilted, eroded, and overlain by horizontally bedded younger gravels; *C*, the older gravels tilted, intersected and overlain by lava, eroded, and again overlain by horizontally bedded younger gravels. 1, Flood-plain deposits; 2, Chemehuevis gravel; 3, Temple Bar (?) conglomerate; 4, igneous rocks.

The older gravels apparently overlie rhyolite and andesite, and at one point a stratum of rhyolitic ash occurs within them. They vary greatly in character from place to place from sandy clay to a breccia with granite bowlders 4 feet in diameter. In general appearance they resemble the Temple Bar conglomerate, and are provisionally correlated with it. This conglomerate is apparently the one which Newberry[a] in the Ives report referred to the Tertiary.

AUBREY CANYON.

Near the southern end of the Chemehuevis Valley the granite of the bordering mountains approaches the river, and at the mouth of Williams River the Colorado enters a narrow canyon, the walls of which are composed of granite overlain by eruptive rock (section *O*, fig. 9). The eruptives west of the canyon were not examined closely, but resemble in general appearance the rhyolite and andesite to the north and the great masses of similar rock composing the Chocolate Mountains to the south. The eruptive rock east of the river is the basalt which caps the Temple Bar conglomerate, as described and illustrated from Williams Canyon (fig. 16).

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[a] Newberry, J. S., Report upon the Colorado River of the West by Lieut. J. C. Ives, pt. 3, 1861, p. 29.

East of Aubrey Canyon, and exposed in the bluffs of Williams Canyon (see p. 54), is an old valley filled to a depth of about 1,000 feet with the Temple Bar conglomerate and covered with 800 feet of basalt. Aubrey Canyon is younger than this gravel-filled valley, having been cut through the basalt sheet covering the Temple Bar conglomerate.

The rock channel in Aubrey Canyon has been cut to a considerable depth beneath the present river level, and filled with sand and gravel. Borings made for the Reclamation Service near the head of the canyon failed to reach bed rock at a depth of 75 feet. In the open basins the river is building flood plains, and the sediment accumulated within the canyon evidently corresponds with that in the open basins, but the maximum depth of this most recent deposit is nowhere indicated.

Here, as elsewhere along Colorado River, there is abundant evidence of a complex physiographic history. A broad valley, described elsewhere as the Detrital-Sacramento Valley (see p. 52), was formed east of Aubrey Canyon and filled to a depth of 1,000 feet or more with sand and gravel—the Temple Bar conglomerate. This was covered with 800 feet or more of basalt, and a new canyon was later eroded west of the old one (section *O*, fig. 9). Still later this canyon was filled with several hundred feet of sand and gravel—Chemehuevis gravel—which were partly carried away by renewed erosion that cut the canyon to a depth lower than the present river level. This channel was in turn filled to its present condition.

GREAT COLORADO VALLEY.

The Great Colorado Valley was examined only in the immediate vicinity of the river during a somewhat hurried excursion by boat, but the data obtained are supplemented to some extent by the investigations of the Reclamation Service. The valley is the largest of the basins through which Colorado River flows, extending, with varying width, from Aubrey Canyon southward to the Chocolate Mountains, a distance of about 75 miles. The Riverside and Halfway mountains form a partial boundary on the west, and the Dome Rock and other mountains on the east; but between the mountain groups occur broad grades, such as the Cactus Plain.

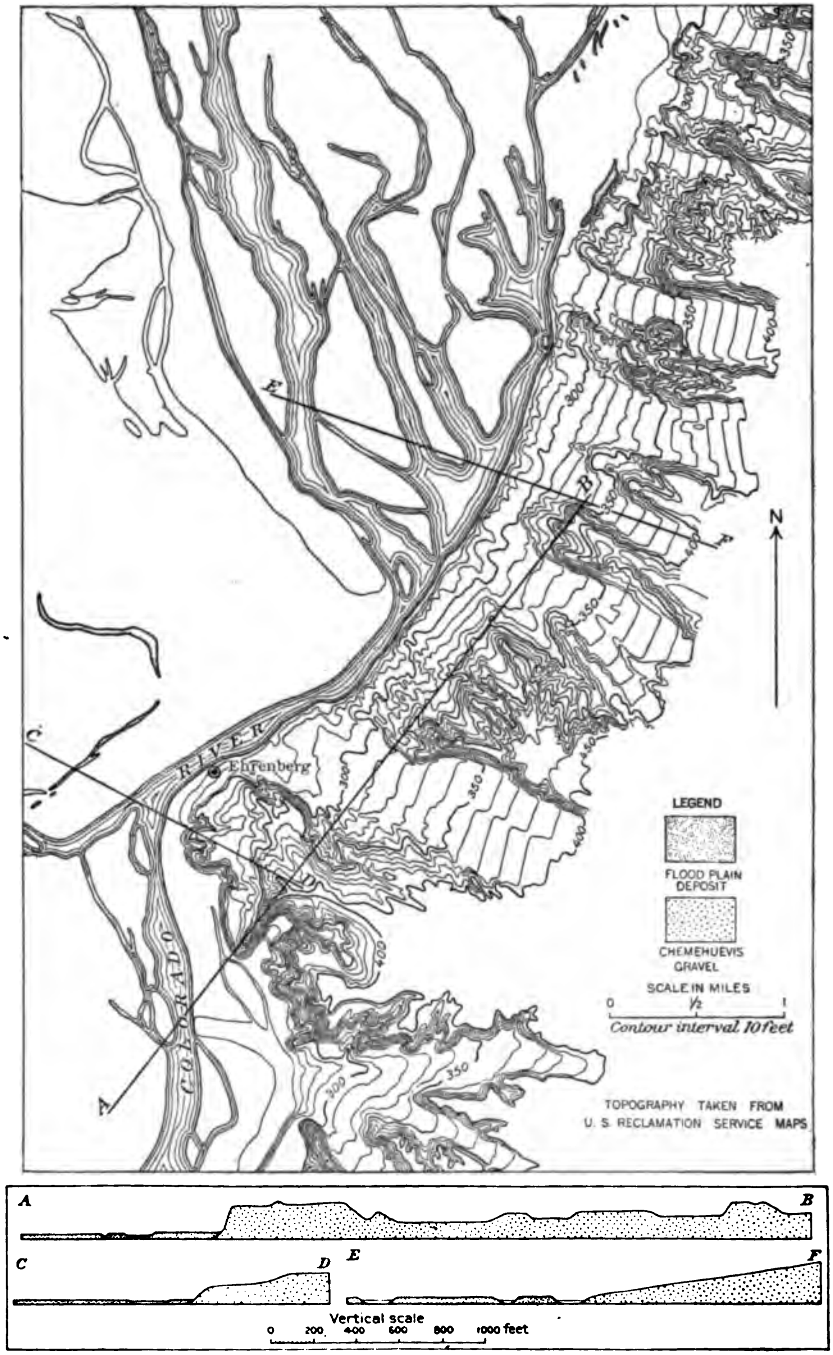

Fig. 12.—Map and sections of a part of the Great Colorado Valley, illustrating the lateral migrations of the river, the relation of the flood plain to the bluffs of the Chemehuevis gravel, and the corrugated slopes at the margins of the valley.

Like the other basins described, the Great Colorado Valley contains gravels representing three distinct epochs of accumulation. The oldest, interpreted as belonging to the Temple Bar conglomerate, was observed near the northern end of the valley, where it is overlain by lava, as at Headgate Rock. Farther to the south, in the middle of the valley, it was not identified.

The younger or Chemehuevis gravel occurs throughout the Great Colorado Valley in conspicuous terraced bluffs. The beds vary much in composition, from a sandy silt to coarse gravel, the finer material greatly predominating. The sand is regularly stratified, cross-bedded, and not distinguishable in physical character or composition from the beds forming at the present time over the flood plain. The Chemehuevis gravel extends for an undetermined distance back from the terraced bluffs, and form corrugated slopes illustrated in fig. 12. The washes entering at the sides of the valley have steeply graded floors, often extending back many miles toward the hills, and are terminated laterally by nearly perpendicular walls. These floors often join laterally, forming wide graded slopes.

From the foot of the gravel bluffs (fig. 12) and extending throughout the valley with a maximum width of 12 miles and a length of 75 miles are flood plains building up by the deposition of sand and silt. Over this great area Colorado River is continually shifting its channel, sometimes gradually by slow cutting and filling and sometimes suddenly by turning through one of the numerous abandoned channels.

The annual floods carry immense quantities of silt, which they spread over the flood plain, building it up with great rapidity. Where the caving banks of the river expose vertical sections it was noted that the roots of living arrow weeds had been buried to a depth of 6 feet or more. In other words, there have been accumulations of silt 6 feet or more in depth during the life of this shrub. The material is well stratified, sometimes with horizontal lamination, but often showing a conspicuous oblique lamination similar to that found in the Chemehuevis gravel. Much of the silt is very fine and is held in suspension for a long time. When deposited in thick beds it dries and cracks in columnar form, some of the columns being 2 to 3 feet in diameter and separated by cracks several inches wide and 2 feet or more deep.

CHOCOLATE MOUNTAINS.

South of the Great Colorado Valley, for a distance of about 30 miles, Colorado River flows in a canyon or narrow valley through the Chocolate Mountains—a name applied generally to a complex group consisting of the Spire Range, the Picacho group, the Castle Dome Mountains, and the Purple Hills.

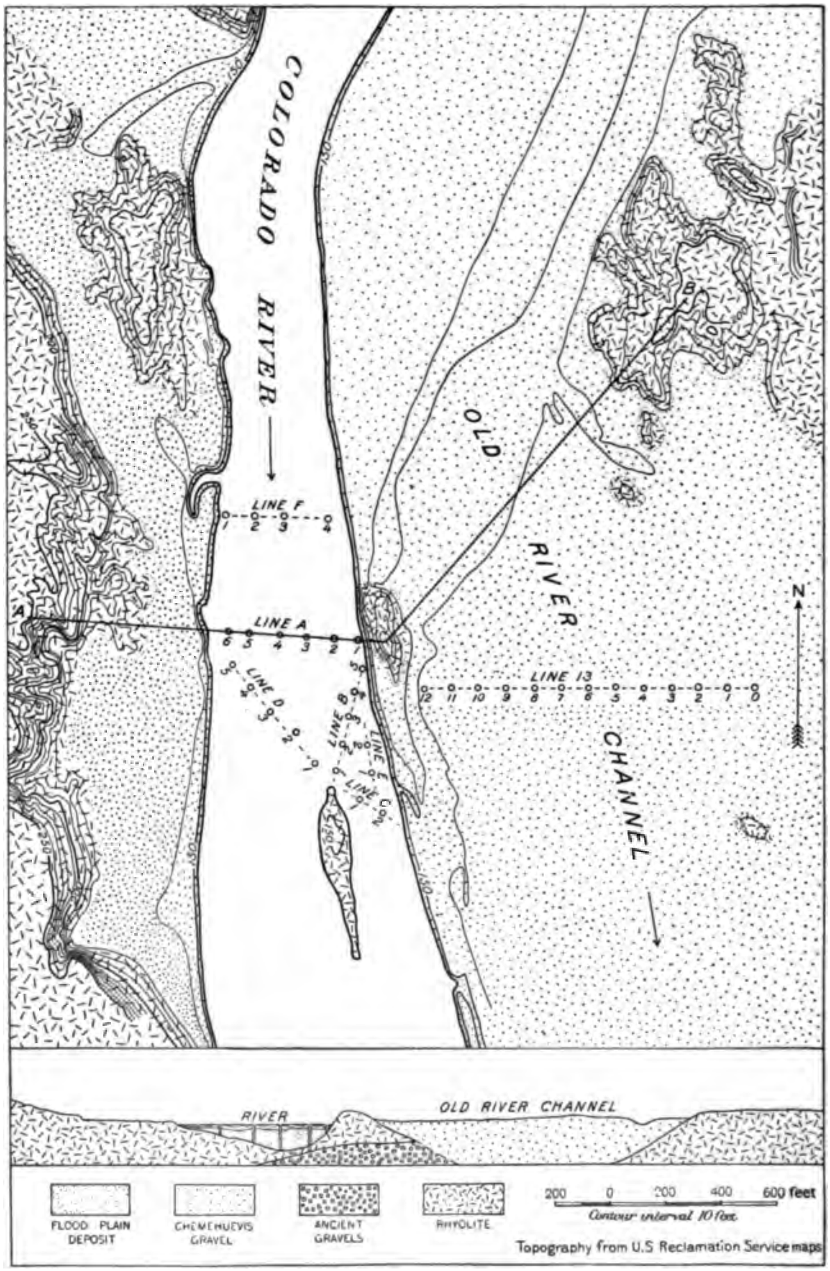

FIG. 13.—Map and section of a part of Chocolate Canyon, showing an old débris-filled channel to the east of the present channel. (Section constructed from boring records.)

The rock exposed along the river is principally effusive, although granite and metamorphosed sediments occur in some places. The effusive rock, consisting of pink and white rhyolite in the form of ash, breccia, and flow, extends from the river level apparently to altitudes of several thousand feet, and is characterized by conspicuous cliffs, erratic forms of erosion, and rock slopes barren of vegetation.

Physiographic changes similar to those at Bulls Head and elsewhere were noted in Chocolate Canyon. At Lighthouse Rock the river has apparently left its old channel and cut laterally into the rhyolite, leaving Lighthouse Rock standing in the water. A boring in the channel at this point failed to reach bed rock at a depth of 80 feet. Farther down the river, near Picacho, several borings in the river bed failed to reach solid rock at a depth of 100 feet.

Probably the best illustration of changes in the course of the river in this vicinity is to be found at the so-called Cacopah dam site of the Reclamation Service, near the southern end of Chocolate Canyon. At this point the Colorado flows close to the rhyolite hills on the west, with one rock island standing in the river and another on the eastern bank. (See fig. 13.) Between these islands and the hills to the east is a broad sand flat.

Borings made at the various places indicated in fig. 13 show that the channel now occupied by the river has been eroded to a depth of about 100 feet, and later filled with sediment, while the old channel to the east is deeper, no solid rock being found at a depth of 138 feet.

A significant observation was made at this point by Homer Hamlin,[a] who noted that in one of the borings the drill penetrated through the rhyolite and entered a gravel bed. (See fig. 13.) The rhyolite is presumably of Tertiary origin, as are also the rhyolites farther north, more fully described elsewhere (p. 83). It is possible that the underlying gravels may be equivalent in age to some of the tilted and consolidated gravels farther north, which were referred by Newberry to the Tertiary, but which the present writer has provisionally correlated with the Temple Bar conglomerate and referred to the Quaternary.

HUALPAI VALLEY.

Location and character.—The Hualpai Valley, about 60 miles long and 25 miles wide, is located in the northeastern part of the region described. Except for a few miles at the northern end, it is an undrained basin, in the lowest part of which flood waters gather and remain until they either evaporate or sink into the valley filling. "Red Lake," thus formed, contains water for periods varying from a few days to several months. At other times it is a broad, barren mud flat.

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[a] Personal communication.

The floor of the Hualpai Valley is nearly level at an altitude of about 3,000 feet and is met on either side by mountain slopes at high angles. The plateau to the east drains away from Hualpai Valley into Colorado River, and the drainage from the White Hills and the Cerbat Mountains to the west and from the Hualpai and Peacock mountains to the south is so small as to be negligible. The only stream worthy of note that enters this great valley is Truxton Creek, the bed of which is usually dry, but which occasionally contains floods of great volume.

Structure.—The Hualpai Valley is a structural trough formed by faulting and block tilting. The Grand Wash fault, with a displacement of 10,000 feet or more at the mouth of Grand Canyon, continues southward into the valley, together with several smaller faults to the west. The general trend of this fault zone in the vicinity of Colorado River, where it is best known, suggests that it may extend through the Hualpai Valley beneath the detrital accumulations and reappear in the fault west of the Hualpai Mountains. On the other hand, extensive displacements by faulting have taken place along the Cottonwood and Aquarius cliffs (see pp. 19–20), and it is possible that these cliffs mark the southward extension of the Grand Wash fault.

At the northern end of the valley the sedimentary formations are tilted steeply to the east; along the eastern flank of the White Hills and Cerbat Mountains the sheets of basalt dip eastward beneath the valley floor. The trough formed by this downthrow to the east has been filled with rock débris to some unknown depth; a well bored 700 feet deep near the head of Hualpai Wash did not pass through it. The material on the alluvial slopes is coarse, but in the center of the valley it is fine and is continually shifted by the winds.

BIG SANDY VALLEY.

Location and character.—The Big Sandy Valley is located between the Aquarius Cliffs on the east and the Hualpai Mountains and Aubrey Hills on the west, and extends from Hackberry southward to Williams River. The lowest part of the valley, known as Big Sandy Wash, lies at the foot of the cliffs as far south as Signal, but at this point the Big Sandy leaves the main valley and passes through Signal Canyon. Several streams of considerable size emerge from the plateau to the east through deep, narrow canyons and discharge into the Big Sandy. The largest of these are White Cliff, Trout, and Sycamore creeks.

That portion of the valley between the Hualpai Mountains and Big Sandy Wash consists of a long, graded detrital slope (see fig. 2, p. 24), more or less deeply cut by parallel washes, such as Deluge Wash. This highly inclined detrital slope, the western fault scarp of the Hualpai Mountains, and the fault scarp to the east (Aquarius Cliffs) all terminate at the south in practically the same latitude. The southern end of the valley, between the Artillery Mountains and the Aubrey Hills, has a slight inclination to the east, but is in general an undissected and undrained detrital plain.

Rock formations.—The oldest rocks in the Big Sandy Valley are the granites exposed in the bordering mountains and cliffs, which, because of their resemblance to the granite beneath the Cambrian sediments in the Grand Wash Cliffs, are thought to be of pre-Cambrian age. They are overlain in places by Tertiary andesites.

The trough formed by these older rocks is partly filled with rock débris which has been later exposed by erosion. The oldest detrital beds have been upturned and eroded to depths of 800 feet or more. They are composed of clay, sand, and gravel, and in places contain granite bowlders 5 to 8 feet in diameter. In other places, as at Deluge Wash (Pl. IV, *B*), they are composed of clay and fine, well-stratified sand and volcanic ash.

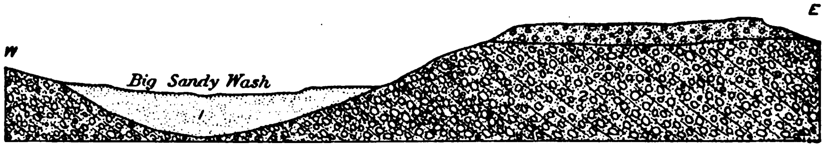


Fig. 14.—Sketch section across Big Sandy Wash near mouth of Deluge Wash, showing the older gravels tilted eastward, eroded, and overlain by younger gravels, and again eroded and partly covered by recent flood-plain deposits. 1, Flood-plain deposits; 2, Temple Bar (?) conglomerate; 3, gravel.

Within the valley eroded in the oldest tilted detrital beds, and resting with horizontal bedding upon their eroded edges, is a second series of gravel deposits. These are perhaps best exposed near the mouth of Deluge Wash, where they are about 50 feet thick. This second gravel accumulation was in turn eroded and a third deposit laid down. (See fig. 14.)

In general character and stratigraphic position the oldest detritus corresponds with the Temple Bar conglomerate, the middle with the Chemehuevis gravel, and the youngest with the flood-plain deposits of the Colorado Valley, but no definite correlation can be made at the present time.

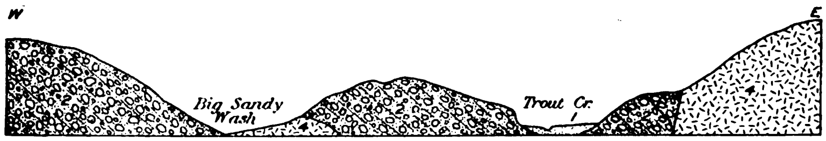


Fig. 15.—Sketch section across Big Sandy Wash at the mouth of Trout Creek, showing the older gravels overlying granite, tilted eastward, and terminating against the granite of Cottonwood Creek. 1, Flood-plain deposits; 2, Temple Bar (?) conglomerate; 4, granite.

Structure.—The Big Sandy Valley is a trough formed by faulting. The fault zone along the Grand Wash and Cottonwood cliffs continues southward to the Aquarius Mountains. Recent movement along this zone is indicated by the displacement of portions of the andesite sheet at the northern end of the valley and by the faulted and tilted gravel beds near the mouth of Trout Creek (fig. 15), where the strata incline

32° to the east and end abruptly against the granite at the fault line. This evidence of faulting, considered in connection with the faulting and block tilting in the Hualpai Mountains, indicates that the Big Sandy Valley was formed by a downthrow of the eastern edge of the Hualpai block. (See fig. 2 and section *S–S'*, Pl. V, p. 24.)

SIGNAL CANYON.

At the town of Signal the Big Sandy leaves the débris-filled trough and passes through a rock gorge known as Signal Canyon. The rocks exposed are coarse-grained granites in the northern part of the canyon and andesites in the southern part. These rocks had been deeply dissected previous to the accumulation of the older detrital beds (just described) which later filled the old valleys and were in turn buried beneath effusive rock. Later, during the erosion of Signal Canyon, these old valleys were reexcavated in part, leaving on the mountain sides conspicuous shelves of lava-covered detritus. (See Pl. III, *A*.)

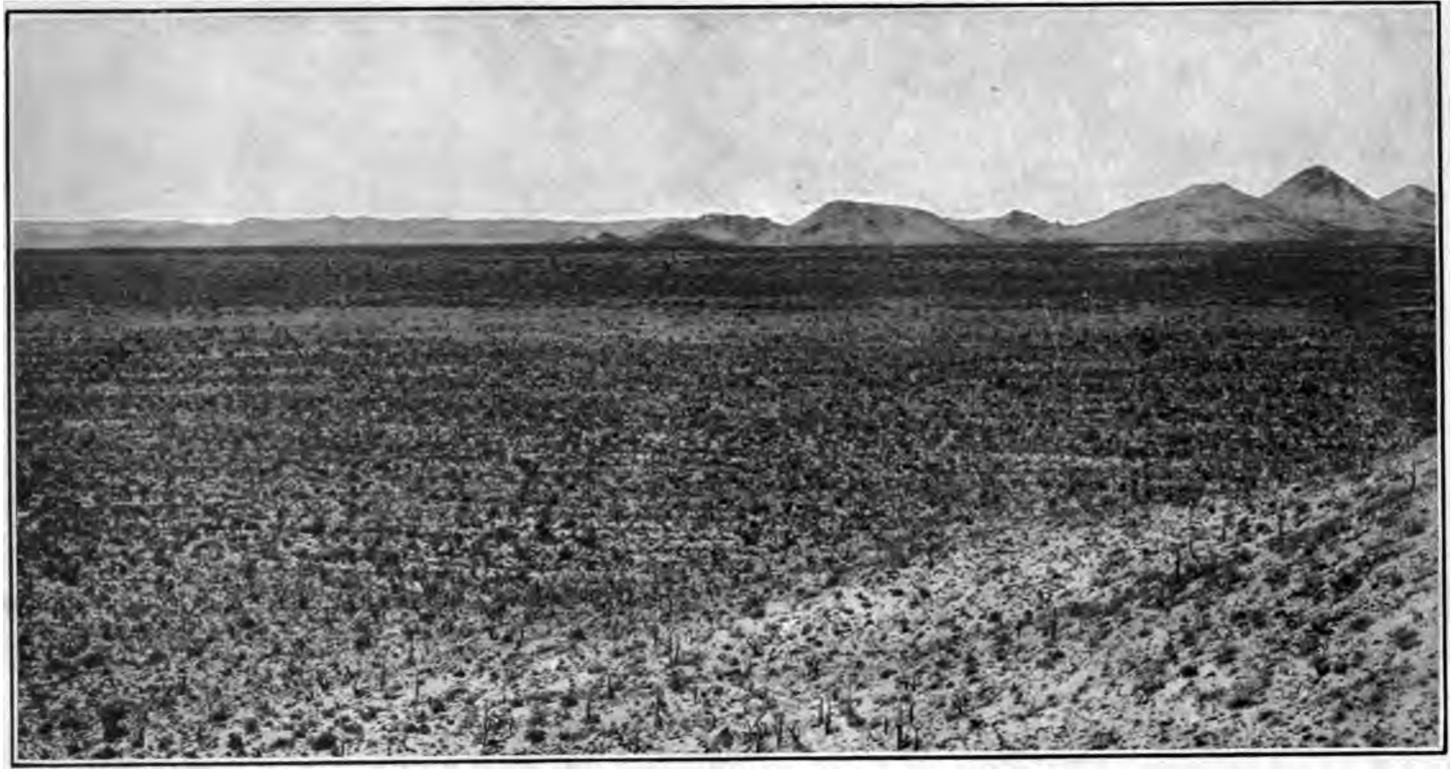
The broad, débris-filled trough here called the Big Sandy Valley continues southward west of the Artillery Mountains to Williams Canyon, where the detritus is seen to extend lower than the bed of Williams River.

DETRITAL-SACRAMENTO VALLEY.

Location and character.—The Detrital-Sacramento Valley extends from Colorado River on the north to Williams River on the south, between the Cerbat and Hualpai mountains to the east and the Black Mountain Range to the west. Thus defined it is about 130 miles long and 5 to 15 miles wide. The northern part of the valley, drained by Detrital Wash, is locally known as the Detrital Valley, and the central part as the Sacramento Valley. (See Pl. XI.) The southern part bears no name, but since it is the southern continuation of the Sacramento Valley, the whole is here called the Detrital-Sacramento Valley.

The valley was apparently formed mainly by erosion, although its form has been modified by crustal movements; such is notably the case west of Chloride, where sheets of basalt, outpoured within the valley, have been tilted eastward. The andesites and rhyolites on either side, from the southern end of Black Mesa northward to Colorado River, are similar in character and occur at about the same level. They are probably remnants of a single effusive mass through which the Detrital-Sacramento Valley was eroded.

The depth to which this valley was cut is not definitely known. At the northern end it was deeper than the present Colorado Valley (altitude 800 feet), and in Williams Canyon (altitude 505 feet) it extends beneath the bed of the river. The maximum depth between



SACRAMENTO VALLEY AT SOUTH END OF HUALPAI MOUNTAINS.

these extremities is not known. At Yucca (altitude 1,804 feet) the bottom of the gravels was reached in a well at a depth of 905 feet, or at an altitude of about 900 feet above sea level. The general altitude of Black Mesa, a few miles west of Yucca, and of the mesa east of the valley near Kingman, is about 3,500 feet. Assuming that the mesas are remnants of the surface which formerly extended across the Detrital-Sacramento Valley, the known depth of erosion at Yucca is about 2,500 feet. Since the valley is known to be deeper than this at both the northern and southern ends, it is probable that the well at Yucca does not penetrate the filling at the deepest point and that the depth of the old valley is greater than 2,500 feet.

Detrital filling.—The Temple Bar conglomerate filling this ancient valley is exposed at the north in the banks of Colorado River (Pl. II) and at the south in Williams Canyon (Pl. VI, *B*). It is composed of horizontally bedded sand, gravel, and wash, and contains sheets of basalt at several horizons. The composition of the filling at the extremities of the valley is described under "Temple Bar" (p. 35), and under "Williams Valley" (p. 54), and need not be repeated here. Where exposed in the washes throughout the valley and penetrated by wells the material does not differ greatly in character. Horizontally bedded sand and gravel containing sheets of basalt and having the same general appearance as the beds at Temple Bar and in Williams Canyon were observed within the valley up to altitudes of 2,500 feet or more, and sheets of basalt within the detrital beds were penetrated in the well at Drake. For these reasons the detrital filling is correlated with the Temple Bar conglomerate.

Considerable erosion has taken place within the Detrital-Sacramento Valley since the filling was completed. Sacramento Wash is 1,000 feet or more lower than the valley floor farther north. This difference in elevation is probably due in part to surface warping, but is regarded as due mainly to erosion.

In general the sands and gravels of the Detrital-Sacramento Valley are covered with angular rock débris, consisting in part of fragments of basalt, andesite, rhyolite, and granite, working their way over the surface as wash from the hills, and in part of the coarser material originally deposited with the sand and gravel and accumulated by surface concentration during the later degradation as the finer material was washed away by the rains or blown away by the winds.

WILLIAMS VALLEY.

Location and character.—Williams River, formerly known as Bill Williams Fork, is formed by the junction of two streams (Big Sandy Wash and Rio Santa Maria) and extends from this junction westward to Colorado River. The south fork, or Rio Santa Maria, emerges through a narrow canyon from the plateau to the east upon a broad detrital plain, into which it has cut a canyon several hundred feet deep. At the point where the river crosses the direct southward continuation of the Big Sandy Valley the canyon has been broadened to a basin several miles wide. About 12 miles east of Planet this basin narrows to a gorge about 8 miles long, known as Williams Canyon. The southern wall continues westward to Colorado River, but the northern wall is broken down west of Planet.

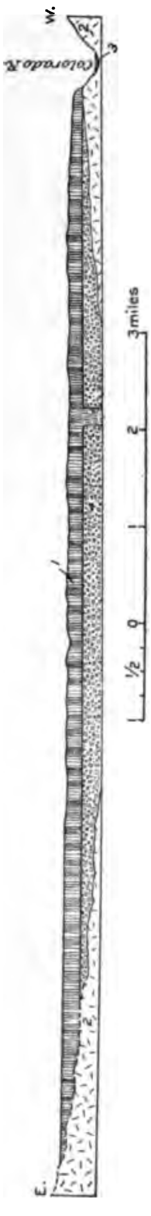


FIG. 16.—Section exposed in the south wall of Williams Canyon, showing the relation of the Colorado Valley to the Detrital-Sacramento Valley. 1, Basalt; 2, crystalline rocks; 3, flood-plain deposits; 4, Temple Bar conglomerate. Horizontal and vertical scale the same.

Although Williams River crosses the Temple Bar conglomerate, filling the Detrital-Sacramento Valley, it has not excavated a broad basin in it, as it has in the gravels filling the Big Sandy Valley, the difference being due to the protection afforded the conglomerate by the sheets of basalt.

Rock formations.—The oldest rock masses exposed in Williams Canyon are gneisses and metamorphosed sediments consisting of quartzites, slates, and limestones associated with beds of iron ore and veins of copper. Within valleys eroded in these rocks occur beds of the Temple Bar conglomerate. In the Detrital-Sacramento Valley, which crosses the Williams Valley, a thickness of nearly 1,000 feet is exposed under a sheet of basalt 800 feet thick. (See fig. 16.) The lowest part of the detritus extends beneath the bed of Williams River, but the underlying gneiss and granite are exposed at the sides of the old valley. The horizontally bedded sand and gravel have been disturbed locally, probably by the eruption of the basalt which burst upward through them.

Geologic section in Williams Canyon, 2 miles east of Colorado River.

	Feet.
Massive flow of basalt	800
Alternating layers of sand and basalt	40
Sand and gravel intersected by basalt dikes	900
Granite gneiss	50

Between the gravels and the massive flow of basalt at the top is a transition zone 40 feet in thickness, containing at the point where the section was made (Pl. VI, *B*) five thin sheets of basalt separated by beds of sand. Each sheet of basalt was outpoured upon what was then the surface, and each in turn was covered by sand. The sand is metamorphosed for a few inches beneath each sheet and contains fragments of scoriaceous basalt immediately above each sheet. The basalt extends completely across the old débris-filled valley to the rock walls on either side.

That the basalt burst upward through the sands and gravels in the midst of the old filled valley is proved by the occurrence of a large dike or neck, about 400 feet wide and several thousand feet long, exposed in the Williams Valley near the point where the section was made. The stratified deposits through which this dike broke are disturbed and burned to a brick red for about 300 feet from the dike. Several smaller dikes occur in the vicinity, and some of the eruptive masses to the north, seen only from a distance, appear to be volcanic necks standing as sharp pinnacles several hundred feet above the level of the surrounding plain.

OTHER VALLEYS.

Location and character.—There are several intermontane plains south of Williams River, known as the Cactus, Posas, and Ranegras plains, McMullan Valley, and an extensive unnamed plain south of the Harquahala Mountains. These are parts of the great desert plains of southwestern Arizona. They are, in part at least, old débris-filled valleys similar to those just described, but their original depth and the character of the filling can be judged only by surface indications. These plains have a general altitude of about 2,000 feet in the eastern half of the area described, and decline gradually westward to Colorado River (altitude 345 feet).

Detrital filling.—Near Williams River the Cactus Plains have been somewhat dissected by erosion; detrital bluffs 500 feet or more in height occur, while the total depth of erosion into the detritus (the difference between the general surface altitude of 2,000 feet and the river elevation of 600 feet) is about 1,400 feet. The bluffs thus exposed are composed of clay, sand, gravel, and angular rock fragments, consisting of granites, andesites, etc., with sheets of embedded basalt. Near the mouth of Date Creek a sheet of basalt about 30 feet thick caps the bluffs, but passes into the detrital beds a short distance back from the face of the cliffs. West of Date Creek two basalt sheets occur in the detrital beds. The lava was outpoured upon an old surface and metamorphosed the material beneath it to some extent. At the surface of each of the lava sheets the cavities contain zeolites, and the overlying sands contain fragments of the basalt, indicating that the gravels and the lavas are contemporaneous.

The detrital material exposed in the bluffs is comparable in thickness and has the same general appearance as the oldest detritus in the Big Sandy Valley and the Temple Bar conglomerate of the Detrital-Sacramento Valley. The basalt sheets embedded in it have the same petrographic character as those contained in the Temple Bar conglomerate (see p. 17) and were supposedly erupted at about the same time. For these reasons the detrital filling is correlated tentatively with the Temple Bar conglomerate.

GEOLOGIC HISTORY.

INTRODUCTORY STATEMENTS.

It is desirable to consider at this point the geologic history of the region—to review the facts that have been presented and to emphasize their significance. Certain considerations which depend upon the interrelations of features at various localities are also presented without reference to former descriptions. The reader should be reminded again that the observations were made during rapid reconnaissance trips and that large intervening areas were not examined. With the exception of the Paleozoic formations of the Plateau region, none of the sediments of northwestern Arizona are fossiliferous so far as observed, and the younger formations can not be traced continuously from place to place. The history of the region is largely one of destructive processes, and the ordinary means of correlation are wanting. For these reasons, although the sequence of the events is apparently clear, their places in the geologic time scale can not now be definitely fixed. The observed facts show that the late geologic history of the region is separable into epochs comparable with those established in neighboring regions, but in the absence of adequate correlation data the intention is to emphasize the sequence of events, the provisional correlations being offered only as a working basis.

PRE-CAMBRIAN CONDITIONS.

Crystalline rocks.—Throughout northwestern Arizona the oldest rocks are coarsely crystalline granites and gneisses. In the plateau to the east the granites underlie the Cambrian sandstone and are intersected by less coarsely crystalline intrusives.

Sedimentation.—The pre-Cambrian sediments so extensively developed in the Grand Canyon region apparently once extended over western Arizona, and remnants of them remain at the northern end of the region near Virgin Canyon and from Williams River southward in the southern part of the area examined.

Base-leveling.—Previous to the deposition of the Cambrian sediments there was a long period of erosion during which such sediments as may have been deposited in the eastern part of the region were removed by erosion and the underlying granites were base-leveled. The line representing this base-level may be followed in the cliffs from Grand Canyon to the southern end of the Juniper Mountains.

PALEOZOIC AND MESOZOIC CONDITIONS.

But little can be said of the history of this region during Paleozoic and Mesozoic time. Cambrian sediments, consisting of sandstone and shale (Tonto formation), underlie the plateau, and were probably deposited over a large part of western Arizona. No Ordovician or Silurian formations have been discovered, and the Devonian of Grand Canyon, described by Walcott,[a] was not identified in the area examined. The Carboniferous is represented by the Redwall limestone, which extends from the Mississippian into the Pennsylvanian, as previously shown in the description of rock formations (pp. 15–16). There is a limited exposure of Carboniferous strata younger than the Redwall in Iceberg Canyon, and Mesozoic formations occur east of the rim of the plateau in a manner which suggests the probability that they originally extended westward over the region described. So far as known, however, no remnants of any of these formations remain west of the cliffs.

Little is known regarding the original extent of the older sedimentary formations in western Arizona or of the circumstances attending their removal. Probably some of the erosion occurred during the Cretaceous period, as suggested by Gilbert,[b] but nothing was found to indicate what proportion of it was accomplished in pre-Tertiary and what in early Tertiary time.

TERTIARY EVENTS.

Explanatory statement.—No great amount of sediment was deposited within the area described during Tertiary time. The period was apparently one of uplift, volcanic activity, and extensive erosion, but it is not known whether the uplift began with the Tertiary or before, nor can the Tertiary be confidently separated from the Quaternary. The sequence of events, based upon physiographic evidence, can be stated with some confidence, but the various epochs can not be confidently referred to established subdivisions of time.

Denudation.—The erosion which removed the older sedimentary formations from western Arizona during early Tertiary and pre-Tertiary time was evidently on an extensive scale. Whatever Paleozoic and Mesozoic sediments had been deposited were stripped off and the underlying granites deeply dissected previous to the eruption of the oldest effusives. The Eocene sediments extensively developed farther north in parts of the plateau region are apparently absent from western Arizona, and the extensive denudation may have been accomplished in large part during Eocene time.

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[a] Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 20, 1880, pp. 221–225.

[b] Gilbert, G. K., U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, pt. 1, p. 134.

Eruption of andesite.—The oldest effusive rock thus far found in western Arizona is the andesite in the vicinity of Gold Roads, a mining camp on Black Mesa, west of Kingman. The andesite rests upon granite and underlies an extensive series of rhyolites and younger andesites, but no further evidence of its age was obtained. It may be a time equivalent of the great masses of andesite comprising the Pine Valley Mountains and resting upon the Eocene sediments in the southwestern part of Utah. These masses, according to Huntington and Goldthwaite,[a] were probably extruded at the close of the Eocene. The provisional reference of the Arizona andesite to the close of the Eocene is based on the fact that, in the general sequence of events here described, its extrusion occurred between the period of early Tertiary erosion and the long period of base-leveling, during which part of the Mohave peneplain was formed. (See p. 59.)

Crustal movements and erosion.—Either during or shortly after the extrusion of the older andesites further uplift apparently occurred in western Arizona, followed by renewed erosion, which carried away much of the andesite and again exposed the granite. The Paleozoic sediments that formerly extended much farther to the west were eroded away at about the same time and the region reduced to a peneplain, parts of which are still preserved in the Truxton Plateau and in the plateau lying south of Iceberg Canyon, in which soft and hard layers alike are truncated. This may prove to be a part of the Mohave peneplain in southwestern Utah, which in the opinion of Huntington and Goldthwaite[b] was formed after the period of folding of the early Miocene.[c]

Certain phenomena described by Spurr,[d] from Meadow Valley Canyon, a tributary of Virgin River in southern Nevada, strengthen this supposition. He describes a succession of rocks very similar to those found in northwestern Arizona. Extensive beds of rhyolite rest on an eroded surface of older rocks and are overlain by extensive deposits of conglomerate and soft sandstone which he refers with a query to the Pliocene, and these in turn are overlain by basalt and Pleistocene gravel. His description of the Pliocene (?) conglomerate and its position in the sections given indicate that it is probably equivalent to the Temple Bar conglomerate, which is here regarded as Pleistocene. Fig. 16 of Spurr's paper shows faulted Paleozoic sediments peneplaned and overlain by the conglomerate. This faulting may prove to be part of the early faulting of the Plateau region, and the peneplain beneath the conglomerate to be part of the Mohave peneplain, in which case the relations in Meadow Valley Wash would correspond with those found in the Plateau region and would form another link in the chain of evidence that the pre-Quaternary course of Colorado River was through southern Nevada, to the north of the present canyon.

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[a] Huntington, Ellsworth, and Goldthwaite, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 42, 1904, p. 217.

[b] Idem, p. 226.

[c] Idem, p. 222.

[d] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: Bull. U. S. Geol. Survey No. 208, 1903, pp. 139-148.

Eruption of rhyolite and younger andesite.—After the formation of the peneplain, extensive masses of rhyolite and andesite, in the form of tuff, breccia, and flow, were spread over its surface, filling the depressions and covering all but the higher parts of the land surface. Although largely removed by later erosion, these lavas still cover wide areas, such as Black Mesa, a large part of the Truxton Plateau, and the mesa in the vicinity of Kingman. These lavas occur also to the east beyond the area described, and far to the south, where they form Castle Dome and the Chocolate Mountains in southwestern Arizona.

In places where the rhyolites and younger andesites occur in more or less regular horizontal beds, as near Kingman and in Black Mesa, they have a maximum thickness of about 3,000 feet. In more mountainous regions, as at the southern end of the Aquarius Mountains, they are apparently thicker. In other places, notably in the Truxton Plateau, they thin and disappear. The thickness of the rhyolites and younger andesites, and their areal distribution, indicate that they originally covered a large part of northwestern Arizona.

The time at which these great masses of igneous rock were extruded is not definitely known. It was after the Mohave peneplain had been formed, at least in large part, for the lavas rest upon the eroded surface. Furthermore, the amount of erosion which followed the extrusion of these lavas places this event far back in the Tertiary. For these reasons, and because of the evidence that the close of the Miocene was a time of mountain forming and of great volcanic disturbance in the Great Basin and the mountains west of it, the extrusions of rhyolites and younger andesites may be provisionally referred to the close of the Miocene.

Formation of the Grand Wash Trough.—Sometime during the middle Tertiary, and apparently before the completion of the Mohave peneplain, the Grand Wash fault was formed, with a displacement of several thousand feet, giving rise to the Grand Wash Trough. This faulting probably corresponds to the early displacements of the Hurricane and other faults described by Huntington and Goldthwaite,[a] and should not be confused with the faulting which accompanied the later uplift of the plateau.

Deposition of the Greggs breccia.—At the north end of the region described local deposition followed the extrusion of the rhyolites and younger andesites. These sediments in the vicinity of Temple Bar lie unconformably beneath the Temple Bar conglomerate and consist mainly of angular fragments of rhyolite, but otherwise are similar in character and stratigraphic position to the Greggs breccia, which, as already stated, consists mainly of granitic débris. Both breccias antedate the present course of Colorado River, which has eroded into them. This correlation would tend to place the Greggs breccia in the Pliocene. On the other hand, the physiographic evidence does not seem to favor this correlation. The rhyolites, supposed to have been erupted at the close of the Miocene, rest upon the peneplain, a fact which tends to place the breccia in the Miocene. It is evident, therefore, that the determination of the age of the Greggs breccia must await further investigation.

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[a] Huntington, Ellsworth, and Goldthwaite, J. W., op. cit., p. 226.

Erosion of the Detrital-Sacramento Valley.—A long period of erosion apparently followed the rhyolitic eruptions and succeeding accumulation of breccia, during which the Detrital-Sacramento Valley was excavated. Measured from the original surface now represented by the mesas on either side, this valley is 5 to 15 miles wide and 3,000 feet deep, including the gravel filling. It extends from southern Nevada southward to Williams River, where it is apparently interrupted by a lava-covered plateau, but its real continuity is shown by the gravel-filling beneath the lava (fig. 16, p. 54). From the plateau southward it is occupied by Colorado River for a distance of 75 miles, in the basin known as the Great Colorado Valley. Owing to circumstances beyond the writer's control, the old valley was not traced south of this basin. It may be pointed out, however, that at the southern end of the basin the river turns abruptly to the east and passes in a narrow rock canyon through the Chocolate Mountains. The general trend of the old valley suggests that it may continue through the hills west of Chocolate Canyon, or perhaps beneath the lavas, and connect with the Gulf of Calfornia (including at that time the Salton Sink), which lies southwest of the Chocolate Mountains.

The origin of the Detrital-Sacramento Valley, although a matter of great interest, can not be fully described until more information is available. It is in a region of profound faulting and surface warping, and may have originated as a succession of depressed areas. But whatever its origin it is believed to have been occupied and greatly modified, if not wholly formed, by a stream of considerable size. The reasons for this belief are as follows:

The beds of volcanic tuff, breccia, and flow in the mesas on either side are composed of the same kinds of rock and are so disposed as to indicate that they may originally have been connected across the intervening space. The width of the valley, 5 to 30 miles, as compared with its length, about 375 miles (including the Great Colorado Valley), together with its somewhat sinuous course, accords more nearly with the conception of a moderately mature river valley than with a succession of downthrown areas. But perhaps the strongest argument in favor of its formation mainly by river erosion is the presence, throughout its length, of sands and gravels similar to those known to have been deposited by aggrading streams.

Relation of Colorado River to the Detrital-Sacramento Valley.—The influence of Colorado River has not been considered thus far for the reason that no clear evidence has been obtained of its presence within the area described. The erosion previously accomplished may have been the work of the Colorado, or may have been accomplished by streams now extinct. But with the erosion of the Detrital-Sacramento Valley the recorded history of the Colorado in western Arizona apparently begins. The river changed its course within the area described during Quaternary time, and there are indications that still greater changes occurred in late Tertiary time; but in order to determine the nature and extent of the changes, it would be necessary to examine a large part of the Plateau region, where, on account of recent faulting, uplift, and subsequent erosion, the investigation would be difficult. There was apparently no great difference in elevation between the Basin region and the southern part of the Plateau region during mid-Tertiary time, the Mohave peneplain extending continuously over both. The evidence of peneplanation in the Meadow Valley and in the Toquerville region, and the general trend of the broad valley of the Virgin heading into this region, suggest that the Colorado may have flowed across what is now the Plateau region to the north of its present course and through the valley now occupied by the lower part of the Virgin into western Arizona, where it excavated the Detrital-Sacramento Valley. A large part of Tertiary time must have been consumed in eroding this great valley. If the formation of the peneplain be correctly assigned to the Miocene, and the extrusion of the rhyolites and younger andesites to the close of this epoch, the erosion of the Detrital-Sacramento Valley must have been accomplished in the Pliocene.

Uplift of the plateau.—The Plateau region seems to have been not notably higher than the area west of it until the end of the epoch during which the Detrital-Sacramento Valley was excavated. But at this time it was greatly elevated and faulted. Extensive displacements occurred along its western border, forming the Grand Wash, Cottonwood, and Aquarius cliffs. Probably the tilting of the great crust blocks like that of the Hualpai Mountains occurred about the same time. The block at Iceberg Canyon, previously upturned, was again tilted, together with the overlying Greggs breccia. The Cerbat Mountains were probably uplifted to some extent, but the principal movement there seems to have been downward, forming Hualpai Valley. About the same time flows of basalt occurred in the Detrital-Sacramento Valley west of Chloride, in the Cerbat Mountains, and elsewhere, which may antedate the crustal movements or may have occurred as accompaniments of the initial movements and later have been tilted to their present position.

Effect of uplift on Colorado River.—The lines of faulting and the axes of uplift were developed across Colorado River and no doubt materially changed its course. Whatever this may have been previously, the uplift of the plateau finally established its direction by causing it to erode the Grand Canyon. In the low-lying region west of the plateau the river flowed across the Grand Wash Trough, previously filled with the Greggs breccia, across the truncated edges of the upturned sediments now exposed in Iceberg Canyon, across a second débris-filled trough near Hualpai Wash, through the crystalline rocks of the Virgin Mountains, and into the previously formed Detrital-Sacramento Valley, which it apparently followed thence to the sea.

The reasons previously given in the detailed descriptions for believing this to be the river's former course may be briefly summarized as follows: Boulder and Black canyons west of the Detrital-Sacramento Valley are apparently younger than Virgin and Iceberg canyons. Remnants of the Temple Bar conglomerate, which occurs typically as the filling of the Detrital-Sacramento Valley, are found in Virgin and Iceberg canyons in positions that indicate deposition after these canyons were eroded; no such occurrence was observed in the canyons west of the Detrital-Sacramento Valley. There are gravel formations similar to the Temple Bar conglomerate west of the Black Mountain range, but they were apparently deposited previous to the erosion of Boulder and Black canyons.

QUATERNARY (?) EVENTS.

First canyon cutting.—During the first epoch of erosion that followed the uplift of the plateau Colorado River eroded Grand Canyon to a depth of 5,000 feet or more beneath the Mohave peneplain. West of the plateau it cut to a depth of somewhat more than 1,400 feet beneath this plain in Iceberg and Virgin canyons. The erosion in the Detrital-Sacramento Valley was probably correspondingly great, but little is known of this on account of the detrital filling of the valley which has not been removed.

The reasons for departing from the usage of former writers who assign the erosion of Grand Canyon to late Tertiary time are twofold: First, the Temple Bar conglomerate, deposited immediately after the first epoch of canyon cutting, is regarded as a Quaternary deposit for reasons stated in the section next following; second, the crustal disturbances resulting in the elevation of the plateau and the erosion of the Grand Canyon were of such magnitude and far-reaching influence in effecting radical changes in the geography and geology of the region that, considering this region alone, without reference to established subdivisions, they appropriately constitute the separation between two great periods of time. Since, therefore, the canyon cutting followed the uplift, it falls into the later or Quaternary period.

Deposition of the Temple Bar conglomerate.—After the canyon had been eroded to something like its present depth some change occurred which caused the river to deposit sand and gravel from Grand Canyon to the Gulf of California. Between the mouth of the canyon and the Detrital-Sacramento Valley no great volume of the gravels accumulated, owing to the limited dimensions of that part of the valley; but in the broad Detrital-Sacramento Valley extensive deposits were laid down to a depth of something like 2,000 feet.

Similar deposits were formed in other valleys of the Southwest, and the low-lying interstream areas were built up with angular rock débris derived from the near-by mountains. As previously described, the detrital formations of various parts of the Territory can not be definitely correlated, but beds apparently equivalent to the Temple Bar conglomerate are found throughout the Southwest.

During this epoch of deposition numerous volcanic eruptions occurred. Sheets of basalt underlie the gravels in some places and in others are included within them at several horizons. Toward the close of the epoch eruptions occurred near the mouth of Williams River, the molten basalt bursting upward through the filling of the Detrital-Sacramento Valley and spreading over its surface to a depth of 800 feet or more, apparently forming a volcanic dam. This sheet has since been greatly eroded and its original extent has not been determined. Lava hills north of Williams River having the appearance of volcanic necks suggest that the center of eruption and the real obstruction across the valley may have been between the Mohave Mountains and the Aubrey Hills, the sheet of compact lava south of Williams River being an outflow from this center.

A dam 800 feet high thrown across Colorado River at this place would have created slack-water conditions not only throughout the entire length of the Detrital-Sacramento Valley, but far into Grand Canyon, and must have facilitated the deposition of sand and gravel, which had previously accumulated in the valley to a depth of about 1,000 feet. The altitude of the basalt sheet does not differ greatly from that of the aggraded floor of the Detrital-Sacramento Valley to the north, and of the sand and gravel remnants found far above the river in the walls of Virgin Canyon. Deposition of sand and gravel apparently continued long after the extrusion of these lavas, filling the Detrital-Sacramento Valley to a level corresponding to the surface of the lava sheet, an additional depth of about 800 feet.

It is probable that the volcanic dam did not at once divert the river from its former course through the Detrital-Sacramento Valley, for the upper part of the valley filling, so far as observed, does not differ in physical character from the lower 1,000 feet, which is presumably a river deposit. The coarseness of the sediment and the absence of terraces along the margin are unfavorable to the supposition that the valley was transformed into a lake separated from the river. It is more probable that the water of the river continued to flow through the temporary lake, filling it rapidly with sediment or even building above the level of the dam before being finally deflected from its former course. A general view of the aggraded valley floor and its relation to the neighboring hills is shown in Pl. XI.

While accumulation was going on in the Detrital-Sacramento Valley other valleys and basins were filling with sediment. The Big Sandy, probably flowing at that time west of the Artillery Mountains and through the Cactus Plains to the Colorado, was evidently building up its course, and the Hualpai Valley, probably at first a lake basin, was filling with sediment. Briefly stated, it is probable that the Temple Bar conglomerate is a part of the widespread accumulation which occupies the low places of the Southwest from central New Mexico to California and northward over the entire basin region. The probability that sedimentation over a wide area was due to a single far-reaching cause or group of causes constitutes one of the principal reasons for correlating the Temple Bar conglomerate with the Lake Bonneville beds and less confidently with the Gila conglomerate. It is not the author's intention to argue that these beds are exact equivalents. They apparently belong, however, to a single division of time, like the Pleistocene epoch of the Quaternary.

It may not be out of place, furthermore, to reiterate the statement that the reconnaissance surveys were inadequate for the final solution of the broad problems which, on account of their local bearing, must of necessity be discussed. The age of the Temple Bar conglomerate and its relation to other similar deposits, the changes in the course and activities of Colorado River, and the causes of these changes, are all problems to be finally solved only after much more extended investigation.

River diversion.—The extensive aggradation caused some of the streams to abandon their old courses, and the sand and gravel filling the valleys were in some cases covered with angular wash. A notable occurrence of the diversion of a river and the burial of its gravels, in the Salt River Valley, has been described by the writer,[a] who shows that Salt River, which now flows north of the Salt River Mountains, formerly joined the Gila east of these mountains, about 40 miles farther upstream.

Colorado River left the Detrital-Sacramento Valley and established a new course west of the Black Mountain Range, from Boulder Canyon to the mouth of Williams River, a distance of about 125 miles. This diversion may have been due in part to the volcanic dam which had been thrown across the Detrital-Sacramento Valley near Williams River; or it may have been caused wholly by the normal deflection of the river over the aggrading surface—an action well illustrated in the frequent changes of course over the flood plains and delta of the Colorado at the present time. It is noteworthy in this connection that the volcanic dam near Williams Canyon, the highest remnants of the detrital beds, and the mountain ridges through which the river cut at Boulder and Black canyons, do not differ greatly in altitude.

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[a] Lee, W. T., Underground waters of Salt River Valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905, pp. 125-127.

Second canyon cutting.—A second epoch of canyon cutting was brought about by some change which caused the streams throughout the Southwest to erode their channels. The streams which had not been deflected from their former courses reexcavated their old valleys; those that had been deflected cut new canyons. Colorado River reexcavated its old valley from Grand Canyon westward to the Detrital-Sacramento Valley, where it left its former course, passing westward across the Black Mountain Range and thence southward to the mouth of Williams River, where it returned to the old valley which it now occupies.

Viewed from the standpoint of existing topography, a more difficult course could scarcely have been selected. Instead of reexcavating the Detrital-Sacramento Valley, where the only hard rock to be eroded was the volcanic dam, it eroded four rock canyons (Boulder, Black, Mohave, and Aubrey) and crossed four débris-filled basins (Las Vegas, Cottonwood, Mohave, and Chemehuevis) before returning to its former course. The excavation of the detritus in the basins was naturally more rapid than the work in the hard rock of the ridges separating them, and the result is the conspicuous alternation of short, sharp canyons and basin-like valleys characteristic of lower Colorado River.

During this epoch the downcutting was apparently very rapid, the rock canyons being narrow, their walls rising abruptly from the water's edge, as in Black Canyon (Pl. VIII, *B*) and in Boulder Canyon. The rapidity of the downcutting is perhaps most strikingly shown where the river has cut through the Temple Bar conglomerate, as at Temple Bar, leaving the poorly consolidated gravels standing in perpendicular cliffs hundreds of feet high. (See Pls. II and VIII, *A*.) The occurrence of these high cliffs of unconsolidated gravel and the absence of extensive weathering are not wholly in accord with the suggestion that the change from the aggrading to the degrading condition of the river was due entirely to a change of climate.

Deposition of Chemehuevis gravel.—Some influence not certainly known brought the second epoch of erosion to a close and caused Colorado River and other streams of the Southwest again to fill their valleys with sand and gravel. The open basins which had been excavated along the Colorado while the canyons were being cut in the harder rock were filled to a depth of several hundred feet with material which has been called the Chemehuevis gravel, and which extends from the mouth of Grand Canyon to the Gulf of California. In the midst of this epoch some change occurred which caused the accumulation of coarser material in the vicinity of Bull Head. This change, however, may have been local, as the division into lower and upper gravels is not conspicuous in other places, so far as observed.

During the accumulation of the Chemehuevis gravel Colorado River evidently shifted its course within narrow limits over the aggrading valley floor, as it had done over a much wider area during the accumulation of the Temple Bar conglomerate.

Third canyon cutting.—When the river again began to erode its channel it reexcavated for the most part the old valley, but in a number of places abandoned its former course and cut rock gorges, leaving the gravel-filled channel at one side, as in Cottonwood Valley (p. 37), Pyramid Canyon (p. 38), Mohave Canyon (p. 42), and Chocolate Canyon (p. 48).

For a third time the river eroded to some unknown depth below its present bed. Borings to a maximum depth of about 200 feet at the dam sites of the Reclamation Service failed to penetrate through the gravels.

Formation of flood plains.—In very recent geologic time Colorado River changed again from a degrading to an aggrading stream, and is once more building up its course. In the broad parts of the valley the accumulation is evidenced by the wide bottom lands over which the river frequently changes its course, sometimes gradually by lateral cutting and filling, and sometimes suddenly by cutting a new channel during a flood, forming numerous sloughs, lagoons, and oxbow lakes.

The great depth of the débris-filled channels within the newest canyons, as shown by the soundings for bed rock, raises the question, What proportion of the depth should be attributed to the normal cutting of the river and what proportion to permanent filling?

Cooley[a] shows that Missouri River at Nebraska City probably erodes its bed to a depth of 70 to 90 feet. Near Omaha the depth of scour and fill during the year 1883 amounted to about 40 feet. On this subject Chamberlin[b] remarks: "In the drift-filled bottoms of the great branches of the Mississippi system it is wholly within bounds to regard at least the upper 40 or 50 feet of the deposit over which the river meanders as subject to scour and fill, and to entertain the suggestion that the deeper portions down to 100 feet or more may be similarly affected."

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[a] Report Chief Eng. U. S. A. for 1879–80, pt. 2, pp. 1060-1071. See also Chamberlin and Salisbury, Text Book of Geology, vol. 1, p. 185.

[b] Chamberlin, T. C., Jour. Geol., vol. 11, 1903, p. 72.

Some instructive data were secured during the construction of bridges across Mississippi and Missouri rivers. N. M. Fenneman[a] has made a special study of this subject and states that the depth of scour, as shown by the occurrence of buried wreckage and also by direct soundings, is 100 feet or more, and that the occurrence of gravels resting on freshly polished rock at a maximum depth of about 335 feet is interpreted as showing that the river transports gravels of considerable size and actively erodes its bed to this great depth. It seems possible, however, that some part of this material may be due to permanent filling in a glacial or preglacial valley, such as are known to exist in the Mississippi Valley.

It is probable that the depth to bed rock shown by the soundings at the various dam sites is largely due to the normal action of the river, cutting deep in times of flood and filling the channel at times of low water. It is equally probable, however, that the channel is to some extent permanently filled.

RÉSUMÉ OF HISTORY.

For convenience of reference, the succession of epochs and their possible time relations are tabulated below.

Table of events in geologic history in western Arizona.

Period.	Epoch.	Deposition epoch.	Erosion epoch.
Quaternary.	Recent	11. Formation of flood plains; accumulation still in progress.	
		10	Rejuvenation of streams; Colorado reexcavates old valley in part and cuts several short rock gorges.
	Pleistocene	9. Deposition of the Chemehuevis gravel.	
		8	Rejuvenation of streams; Colorado River, flowing west of the Black Mountains, lowers its bed 2,000 feet or more and cuts Aubrey, Mohave, Black, and Boulder canyons.
		7. Widespread aggradation and volcanic eruption. About 2,000 feet of the Temple Bar conglomerate deposited.	
		6	Uplift of the Colorado Plateau; erosion of Grand Canyon; flow of Colorado River in the Detrital-Sacramento Valley.
?	?	?	?
Tertiary.	Pliocene	5	Erosion of the Detrital-Sacramento and other valleys.
	Miocene	4. Local deposition; eruption of rhyolite and andesite.	
		3	Peneplanation and recession of the Yampai Cliffs.
	Eocene	2. Eruption of andesite.	
		1	General degradation.

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[a] Personal communication.

CORRELATIONS.

Explanatory statements.—Although no definite correlations can be made between the products of deposition and erosion of this and other regions, there are certain presumptions worthy of consideration. The succession of Quaternary events in western Arizona is similar to that of the Lake Bonneville and other inland regions, and the long epochs of erosion and thick deposits of sediment represent comparable lengths of time for each region. Western Arizona is a part of the great area of western America which underwent extensive changes of elevation during Tertiary and Quaternary time, the various epochs of which were recorded in marine deposition and erosion along the Pacific coast. Since western Arizona is a part of the Pacific drainage area, although far inland, it is presumably true that the great epochs of the coast correspond in some measure with the great epochs of the interior, inasmuch as the thick marine deposits must represent long periods of erosion of the land areas.

Comparison with Lake Bonneville history.—In his summary of the history of the Lake Bonneville oscillations Gilbert [a] enumerates the following events, given in order from oldest to youngest:

1. Erosion. Gilbert says: "This we may call the pre-Bonneville low-water epoch. It was of great duration compared with those enumerated below."
2. Deposition. First Bonneville epoch of high water; deposits of Yellow Clay. This epoch is estimated (p. 316) as being five times as long as the second epoch of deposition (4).
3. Erosion. Represented by unconformity and by alluvial deposits. The duration is estimated (p. 316) as greater than that of the final retreat of the water (5).
4. Deposition. Second Bonneville epoch of high water; deposit of White Marl.
5. Final retreat of water, intermittently, to present stage.

The thickness of the Lake Bonneville beds was not known at the time of Gilbert's writings, nor is their maximum thickness yet determined. Boutwell [b] has shown that a 2,000-foot well at the eastern margin of Salt Lake, near Farmington (altitude 4,231 feet), does not penetrate through the fragmental beds. A similar thickness of sediments has recently been found in a deep boring at Neels, Utah (altitude 4,621 feet), a station on the San Pedro, Los Angeles and Salt Lake Railroad east of Sevier Lake. The well, which was completed in 1906, is 1,998 feet deep and penetrates 1,944 feet of sedimentary matter before reaching bed rock, which is granite.

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[a] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, p. 259.

[b] Boutwell, J. M., Oil and asphalt prospects in Salt Lake basin: Bull. U. S. Geol. Survey No. 260, 1904, p. 471.

A driller's record, which was apparently kept with exceptional care, exhibits no change in character to indicate that the lower part of the beds are pre-Bonneville in age. It is worthy of note that Neels is located in the narrow neck of Lake Bonneville that connected Escalante Bay with the larger body of water to the north, as shown in Gilbert's map (Pl. III of the Lake Bonneville monograph). It is probable that the broader parts of the lake were much deeper than this narrow strait, and that the sediments filling them were correspondingly thicker.

Because of the importance of this well in showing the character and depth of the Lake Bonneville sediments, the driller's record is here given:

Record of San Pedro, Los Angeles and Salt Lake Railroad well at Neels, Utah.

	Thickness (feet).	Depth (feet).
Surface soil	4	4
Sedimentary (alkali)	5	9
Fire clay	40	49
Water-bearing quicksand	9	58
Shale and soapstone	21	79
Rock (sedimentary)	6	85
Water-bearing quicksand	3	88
Soapstone	11	99
Soapstone with fossil bowlders	39	138
Water-bearing quicksand	4	142
Fire clay	12	154
Blue waxy clay	34	188
Gray shale and clay mixed	7	195
Gray waxy clay	36	231
Lava rock	12	243
Blue waxy clay	12	255
Sedimentary sandstone	6	261
Blue waxy clay	25	286
Water-bearing quicksand	6	292
Blue waxy clay	28	320
Water-bearing quicksand	7	327
Sedimentary sandstone	10	337
Yellow clay	16	353
Water-bearing quicksand	5	358
Yellow clay	27	385
Blue waxy clay	110	495
Yellow clay	15	510
Sedimentary sandstone	24	534
Blue waxy clay	17	551
Soapstone	50	601
Blue waxy clay	11	612
Silt	8	620
Water-bearing quicksand	3	623
Yellow clay	53	676
Sedimentary sandstone	12	688

	Thickness (feet).	Depth (feet).
Yellow clay	34	722
Blue waxy clay	117	839
Yellow clay	9	848
Blue waxy clay	210	1,058
Blue shale (sand mixed)	18	1,076
Blue waxy clay	13	1,089
Blue shale	45	1,134
Blue shale (sand mixed), yielded hot water	71	1,205
Red shale	12	1,217
Blue shale	70	1,287
Red shale	24	1,311
Blue shale	28	1,339
Red "keel" stone	6	1,345
Water, sand, gravel, and bowlders	70	1,415
Sedimentary sandstone (brown)	35	1,450
Red sandstone	95	1,545
Red shale (burned)	35	1,580
Trap rock (dark brown)	36	1,616
Red shale (burned)	56	1,672
Lava rock with calcite crystals	14	1,686
Red sandstone	68	1,754
Red clay (sticky)	48	1,802
Volcanic deposit, ash, and bowlders	105	1,907
(Gas under pressure sufficient to raise 6,200 pounds of tools 400 feet.)		
Bowlders (cemented)	6	1,913
Cavity	9	1,922
Bowlders	22	1,944
Cavity	6	1,950
Granite with cavities and gas	48	1,998
	1,998	

At the risk of carrying comparisons too far, attention is called to the possible correspondence between the Quaternary epochs of western Arizona and those of the Lake Bonneville basin. The high stages of Lake Bonneville have been explained as being due to the changes of climate toward increasing precipitation, and the low-water stages toward increasing aridity. Periods of great precipitation (and high water in an undrained lake) are those of active stream erosion, and, other things being equal, the periods of sedimentation in Lake Bonneville should be the periods of stream erosion in neighboring regions. On this assumption Gilbert's first Bonneville epoch of high water, during which 2,000 feet or more of sediment consisting largely of fine material was deposited, seems to correspond in duration and position in the time scale to the erosion of Grand Canyon (epoch 6 of the Arizona scale); his first epoch of low water, to the deposition of the Temple Bar conglomerate; his second Bonneville epoch of high water, to the erosion of Black and Boulder canyons (epoch 8 of Arizona); and his final epoch of desiccation, which was accomplished intermittently, to the deposition of the Chemehuevis gravel and the following minor epochs represented along lower Colorado River. Whether so close a parallelism of events is warrantable or not, it is evident that the general sequence of events as recorded in the Bonneville basin is similar to that of the Colorado Valley.

Comparison with southern California.—Hershey[a] has arrived at a conclusion regarding the length of Quaternary time and the complexity of its history which is similar in a general way to that shown by the epochs of the Bonneville basin and of western Arizona. Probably the most significant feature of his subdivisions in relation to the phenomena of western Arizona is a long epoch of erosion at the beginning of the Quaternary, which in his opinion is much longer than all the subsequent epochs combined. This epoch may, on further study, prove to be equivalent in point of time to the erosion of Grand Canyon.

Comparison with the Pacific coast.—In studies of the marine beds of the Pacific coast, Arnold[b] shows that, while the epochs of the Tertiary and Quaternary are very fully represented, the subdivisions do not conform in all cases to those of the standard time scale. The division of Tertiary time as given in his publications, which in personal interviews he asserts will hold good for the Pacific coast generally, is shown in the following table:

Correlation table of the marine Tertiary and Pleistocene formations of the Pacific coast.

Period.	Epoch.	Formation.[c]
Quaternary	Pleistocene	San Pedro, 1,000 ± feet.
Tertiary	Pliocene	Merced, 5,000 ± feet.
		Purisima, 800 ± feet.
	Transitional	
	Miocene	San Pablo, 1,500 to 2,000 feet.
		Monterey, 2,500 ± feet.
		Vaqueros, 3,000 ± feet.
	Oligocene	San Lorenzo, 2,300 ± feet.
	Eocene	Tejon, 4,000 ± feet.
		Martinez, 1,000 to 2,000 feet.

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[a] Hershey, O. H., The Quaternary of southern California: Bull. Univ. California Dept. Geol., vol. 3, 1902, pp. 1-30.

[b] Arnold, Ralph, The Tertiary and Quaternary pectens of California: Prof. Paper U. S. Geol. Survey No. 47, 1906, p. 9.

[c] In this column full lines represent unconformity; broken lines, conformity.

According to Arnold, the great time breaks occurred: (a) At the close of the Eocene, the break in this case being indicated by a distinct change of fauna; (b) before the close of the Miocene; and (c) sometime during the Quaternary, the latter two being erosion breaks. It seems probable that the long periods of sedimentation along the Pacific coast may be equivalent in a general way to the periods of quiet erosion described in western Arizona, and that the great and widely recognizable unconformities of the coast may correspond to the periods of crustal disturbances and volcanic activity of the interior. Thus the long period of erosion resulting in the formation of the Mohave peneplain may correspond to the deposition of the Vaqueros and Monterey formations, and the eruptions of rhyolite in Arizona to the unconformity between the San Pablo and the Monterey, which is associated with the volcanic eruptions of the coast region.

The similarity in succession of Quaternary events in the two regions is not striking. Pleistocene time is represented on the coast by thick sediments and Recent time by some of the raised sea beeches. The thickness of the Pleistocene sediments renders it probable that the time required for their deposition is comparable with the long period of erosion during early Quaternary in the Arizona region, and the relative position of these epochs in the time scale apparently warrants provisional correlation. The terraces of the coast may correspond in time with the various epochs of erosion and deposition of the Arizona region.

Comparison with the Plateau region.—In the Plateau region the subdivision of Tertiary and Quaternary time is based mainly on physiographic evidence. Davis[a] has shown that there were two main cycles of erosion, designated the plateau cycle and the canyon cycle. During the first or plateau cycle a large area in northern Arizona and southern Utah was reduced to a peneplain. The original surface of this peneplain is preserved in places by lava flows, as on the Shiwitz Plateau in northern Arizona and near Toquerville, Utah,[b] but has generally been dissected by later erosion. The peneplain will perhaps be best recognized—if due allowance be made for subsequent erosion—as the surface of the plateau in which Grand Canyon is eroded in northern Arizona. During the second or canyon cycle Grand Canyon was carved by the Colorado, and the peneplain, now elevated, was dissected to a less extent by the smaller streams.

Following Davis, Huntington and Goldthwaite in their description of the Toquerville region of southwestern Utah emphasize the importance of these cycles and add many details which aid in studying the geologic history of the Grand Canyon region. The succession of Tertiary and Quaternary events described by them may be summarized, in order from oldest to youngest, as follows:

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[a] Davis, W. M., An excursion to the Grand Canyon of the Colorado: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 38, 1901, pp. 107-201.

[b] Huntington, Ellsworth, and Goldthwaite, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 42, 1904, p. 231.

1. Eocene. A period of deposition during which the Plateau region was low.
2. A period of elevation accompanied by folding, flexing, and extrusion of andesite.
3. A second period of erosion—the pre-fault cycle.
4. Earlier faulting, during which the great faults of the Plateau region, such as Hurricane and Grand Wash faults, were originally formed.
5. Interfault cycle of erosion, during which the Mohave peneplain was formed.
6. Later faulting and final uplift of the High Plateau.
7. Erosion of Grand Canyon.

The history thus developed corresponds in many ways with that of western Arizona, but differs notably in some respects. The early Tertiary erosion in western Arizona seems to correspond in time with the Eocene sedimentation of the plateaus, and eruptions of andesite marked the close of the period of both provinces. There is, furthermore, no disagreement regarding the time of uplift and faulting immediately preceding the erosion of Grand Canyon, but further investigation is necessary before the subdivision of middle and later Tertiary time in the two provinces can be harmonized. Apparently, the great masses of rhyolite, 3,000 feet thick in western Arizona and presumably extruded at the close of the Miocene, were not found in southwestern Utah, and the long period of erosion which followed their extrusion, presumably during Pliocene time, seems to be included by Huntington and Goldthwaite in the time during which the Mohave peneplain was being formed, since according to them this cycle of erosion ended with the uplift of the plateau and the origin of Grand Canyon.

Since the Mohave peneplain is here used as a correlation horizon, it may be in place to inquire into its probable extent. As already stated, this peneplain, which in the Plateau region of southern Utah and northern Arizona is represented by the platform at the top of Grand Canyon, is here regarded as extending generally over northwestern Arizona. A similar peneplain has been described by Lindgren[a] in the Sierra region of eastern California, where he finds evidence of an extensive peneplain, formed presumably during the Miocene and covered in part by the younger auriferous gravels, and these in turn by rhyolites and andesites—a sequence which corresponds with that in northwestern Arizona. Other localities might be referred to in which mid-Tertiary erosion may correspond in time with the formation of the Mohave peneplain. In view, however, of the great distances between the various localities described and the difficulties of correlating periods of erosion, the most that can be said is that the available evidence points to the probability that the Mohave peneplain was one of great extent and may prove to be a valuable means of correlation.

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[a] Lindgren, Waldemar, Age of the auriferous gravels of the Sierra Nevada: Jour. Geology, vol. 5, 1896, pp. 881-906.

WATER SUPPLIES.

SURFACE WATERS.

PRECIPITATION.

Little is definitely known of the rainfall in western Arizona. According to E. C. Murphy,[a] of the U. S. Geological Survey, the average annual precipitation for the region is approximately 5 inches. At Needles, Cal., records kept by the Weather Bureau since 1892 show an annual mean of 2.47 inches.

EVAPORATION.

Evaporation in western Arizona greatly exceeds rainfall. No records are available for the area described, but it probably does not differ very much from that at Yuma, Ariz., where the annual evaporation, as given by Murphy, is 82.32 inches.

STREAMS.

COLORADO RIVER.

Flow.—A gaging station has recently been established at Hardyville, near old Fort Mohave, for measuring the flow of Colorado River. Records, however, are already available for the last four years at Yuma, Ariz., which probably give most satisfactorily the volume carried by the lower Colorado.

Discharge of Colorado River at Yuma, Ariz.

	Total in acre-feet.	Mean in second-feet.
1902	7,960,189	10,970
1903	11,329,032	15,595
1904	10,109,004	13,922
1905	19,710,000	27,300
Average	12,277,056	16,947

Irrigable lands.—Although a large amount of water is available in Colorado River, the irrigable land is limited in amount and confined to the flood plains. According to Homer Hamlin,[a] of the Reclamation Service, the acreage is distributed as follows:

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[a] Personal communication.

Irrigable land along Colorado River.

	Acres.
Cottonwood Valley	5,000
Mohave Valley	50,000
Chemehuevis Valley	20,000
Great Colorado Valley	200,000
Yuma Valley	100,000
	375,000

The ways and means of irrigating these lands have been investigated by the Reclamation Service, but except for the Yuma project, now under construction, no development has yet been undertaken.

Outside of the flood plains no lands within the area described are sufficiently low to be irrigated from the river. The broad valleys and detrital plains occupying so large a part of the region, although admirably adapted to agriculture in other respects, are too high to be economically supplied with water from Colorado River by any means known at the present time. In order to water the Hualpai or Detrital valleys it would be necessary to raise the water of the river about 2,000 feet, and the case is nearly as hopeless for the valleys farther south.

Dam sites.—Several dam sites have been selected along Colorado River by the engineers of the Reclamation Service, and much has been done in the way of investigation as far north as the Cottonwood Valley. Possible dam sites occur in Chocolate Canyon (fig. 13), Aubrey Canyon, at Bulls Head in Pyramid Canyon (Pl. IX), and at Eagle Rock in the Cottonwood Valley (fig. 7). In none of these localities, however, has bed rock been found sufficiently near the surface to warrant the construction of masonry dams. In Chocolate Canyon borings reached the depth of 138 feet; in Aubrey Canyon, 75 feet; in Pyramid Canyon, 100 feet. But in no case was the maximum depth of the old gravel-filled channel reached.

The canyons north of the Cottonwood Valley offer excellent opportunities for the construction of dams, but little has been done further than the selection of certain favorable localities. Several have been selected by the Reclamation Service, and others by private companies who contemplate using the water power in developing the mineral resources of the region. The questions involved are mainly of an engineering nature, but it may be in place here to describe certain geologic conditions that are likely to affect development.

In Recent time—the last epoch described under "Geologic history"—the river has been filling its channel, at least in its lower reaches. It is evident, therefore, that even in the newest channels, such as that at Bulls Head, bed rock is not to be expected as near the surface as it would be if the river were in an eroding stage. In other words, it is probable that the rock channel is deeper than the maximum depth of scour.

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[a] Personal communication.

The flood-plain deposits, so conspicuous in the lower reaches of the river, become less conspicuous upstream, until in Black Canyon rapids of notable proportions occur. In the absence of soundings in the channel for bed rock farther north than Bulls Head, it is impossible to say that the channel is not filled in the northern portion of the region as it is farther south where soundings have been made. The swift current washes the fine material away and leaves large bowlders clogging the channel even where the grade of the river is steep enough to form dangerous rapids. It is the writer's impression that the river is flowing essentially on rock bottom through Black, Boulder, Virgin, and Iceberg canyons, with only such obstructions of bowlders as are incidental to variations in the river's power of transportation; in other words, that there is no permanent filling in the bottom of those canyons.

The deflection of the river previously described has resulted in the cutting of young channels in many places for short distances, as at Eagle Rock, Bulls Head, Great Bend, etc. It is in these young channels that bed rock is to be expected at the least depth. The relation, however, to the old débris-filled channel at the side may be such as to influence this depth. For example, at Bulls Head the depth to bed rock in the channel now occupied by the river might be greater near the edge of the old channel, owing to the fact that the new channel might coincide with some lateral wash of the old, while north of Bulls Head Rock, midway of the young channel, bed rock might be much nearer the surface. The depth to which a large river works is known to be great, although there is little information at present to indicate the maximum depth to which Colorado River works. The records of Missouri River, previously cited (p. 66), indicate the possibility that a depth of 73 to 100 feet, or even more in narrow channels, such as that at Bulls Head, is to be expected as a result of river abrasion alone.

Considering further the depth of scour, it is evident that the river will cut to a less depth in wide passages than in narrow passages where the current is swift. The narrow places are usually selected as dam sites on account of the presence of favorable abutments comparatively close together. It is possible that in certain cases the depth to bed rock in the wide part of a gorge, where the abrasive force is weak owing to a diminution of velocity, might be enough less than in the narrow parts, where the current is swift, to more than compensate for the greater length of a dam.

BIG SANDY WASH AND WILLIAMS RIVER.

Big Sandy Wash has a small permanent flow, and Williams River furnishes water for the irrigation of a few ranches, but the floods of Williams River are evidently large. Water marks on the rocks and drift material lodged in the face of the canyon walls are seen at the height of 20 feet or more above the bed of the stream. The quantity of water discharged by Williams River is apparently sufficient to warrant the construction of a reservoir in the basin east of Williams Canyon. This basin is about 7 miles long and 5 miles wide, and the gorge forming a possible dam site is about 60 feet wide at the water line.

A reservoir at this place would be of comparatively little use in irrigation, as there is practically no irrigable land available. It might, however, be of great benefit in producing power for the development of the mineral resources. Rich deposits of gold, copper, and iron are known to occur in this region, but development is hindered or wholly prevented by the want of transportation facilities. The production of power, such as seems possible in this locality, might be the means of developing a rich mining district.

UNDERGROUND WATERS.

SURFACE INDICATIONS.

In many places throughout the Southwest the unconsolidated deposits filling the old valleys and intermontane basins are saturated with water, and the hope was entertained that this might be the case in the area here described. The geography of the region, however, is not favorable for the accumulation of large quantities of underground water, nor for the retention of such as might accumulate. The rainfall is slight and no large quantities can be derived from streams. Colorado Canyon on the north and west forms an effectual outlet for waters which might otherwise accumulate in the gravels.

From surface indications the Hualpai Valley would seem to have an underground water supply. It is an undrained basin into which Truxton Creek empties, and contains standing water for considerable periods. Only one well has been bored in the valley, at its northern extremity in Hualpai Wash. The absence of water in this well is not considered proof that water may not exist near the surface in the center of the valley.

In the other valleys and plains of the region the prospect is not encouraging. There is little opportunity for the accumulation of water in the gravels of the Cactus Plains, because of drainage into Colorado River to the west and Williams Canyon to the north. Conditions in the McMullen Valley are slightly more favorable, but water is found only at depths of 100 feet or more. No wells are reported from the plains south of Harrisburg.

WELLS.

Nelson.—The well at Nelson, Ariz., is 1,043 feet deep. At 516 feet a little water was found, and in the sandstone near the bottom a larger supply was encountered; but the available quantity has not been ascertained. The formations passed through are as follows:

Log of railroad well at Nelson, Ariz.

	Feet.
Cemented detritus	0- 44
Limestone (Redwall)	44- 396
Sandstone and shale (Tonto)	396-1,043

Peach Springs.—A well at Peach Springs, Ariz., is 920 feet deep. A small amount of water was encountered somewhere in the lower half, but the horizon is not known. Water stands at a depth of 413 feet, and a preliminary pumping test yielded 25 gallons per minute, or 14,000 gallons per day of twenty-four hours. This is insufficient for railway use, and the well is to be sunk deeper. The formations passed through are as follows:

Log of railroad well at Peach Springs, Ariz.

	Feet.
Cemented gravel	0-200
Limestone (Redwall)	200-560
Shale (Tonto)	560-920

Hackberry.—There are several dug wells at Hackberry, Ariz., in or near the bed of Truxton Creek. They penetrate through the detritus and encounter granite at a depth of about 70 feet, where a limited flow of water is obtained. The well at the railway station is taxed to its extreme limit in supplying 80,000 gallons in twenty-four hours, or 55 gallons per minute.

Kingman.—There are about 60 wells in the town of Kingman. A few of these are dug, but most of them are drilled. They are from 120 to 200 feet in depth, according to the difference in surface elevation. The water occurs in a bed of volcanic tuff about 30 feet thick, which rests upon the granite. An abundance of water is obtained from these wells to supply the needs of the railroad and the town.

Gold Basin.—Two wells 500 and 700 feet deep were drilled several years ago in Gold Basin at the northern end of the Hualpai Valley, about 50 miles north of Kingman. Nothing but detrital material was penetrated, and no water was encountered.

Drake.—The well at Drake, in the Sacramento Valley, is 687 feet deep and penetrates to bed rock. Water was encountered at a depth of 430 feet in "gray granite" and rose 30 feet. (This material is undoubtedly granitic wash, cemented by carbonate of lime. Cemented material of this kind is common in the Quaternary deposits throughout the arid regions. The yield of the well has not been determined.

Log of railroad well at Drake, Ariz.

	Feet.
Sand and bowlders	0- 45
Brown sand	45- 90
Bowlders	90-160
Brown sand	160-178
Sand and gravel	178-223
Black lava	223-308
Yellow sand	308-368
Black lava	368-408
Flint	408-414
Black lava	414-419
Gray granite	419-475
Black lava	475-483
"Gray granite," water bearing	483-537
Clay,	537-578
Disintegrated granite	578-603
Solid granite	603-687

Yucca.—There are two deep wells at Yucca, situated near Sacramento Wash. The first was drilled in 1889 and has been in operation since that time. The amount of water obtainable was not sufficient for the needs at that point, and a second well has been put down to a depth of 1,004 feet. Water is said to have been encountered at a depth of 310 feet, but when measured by the writer in the new well it was standing at a depth of 346 feet. No special water-bearing stratum was encountered below the first, and the additional supply is obtained by slow seepage through the sand and gravel. The material encountered is as follows:

Log of railroad well at Yucca, Ariz.

	Feet.
Cemented sand and gravel	0- 370
Clay	370- 455
Gravel	455- 555
White sand	555- 905
Granite	905-1,004

Haviland.—The well at Haviland is 505 feet deep and is in volcanic material most of the way. Water was encountered at a depth of 248 feet and rose 48 feet. The well yields 60,000 gallons of water per day, or about 42 gallons per minute. The material penetrated is as follows:

Log of railroad well at Haviland, Ariz.

	Feet.
Bowlders	0- 12
Lava	12-260
White volcanic tuff	260-505

Big Sandy Valley.—Several wells dug in Big Sandy Wash encountered water 15 to 75 feet below the surface, according to locality. It is reported that a few years ago water was sufficiently near the surface to seep into the lower places along the bottom of the valley, where it was used for irrigation; but during the last few years this seepage has disappeared.

Harrisburg.—Near Harrisburg, at the point where the wash draining the McMullen Valley passes through the constriction between the mountains, a centrifugal pump has been established, and water is obtained in sufficient quantities to irrigate a small ranch. This supply is local and limited in amount.

Other wells.—At a number of places in McMullen Valley, in the Cactus Plain, and in the plains of the southern extremity of the region, wells were reported; but nowhere was ground water encountered in sufficient quantities or near enough to the surface to warrant any attempt at development for irrigation.

Records of railway wells in northeastern Arizona.

Location.	Depth.	Diameter.	Year completed.	Depth to water.	Water raised by—	Amount raised in 24 hours.	Remarks.
	Feet.	*Inches.*		*Feet.*		*Gallons.*	
Haviland	505	12	1901	200	Air lift	60,000	
Yucca No. 1	534	10	1889	346	do	[a] 90,000	36,000 gallons per day is all that can now be pumped.
Yucca No. 2	1,004	13	1903	346	do	Not tested.	
Kingman	120-200	Dug.	(?)	(?)	Steam pump		
Drake	684	12	1901	400	Air lift	Not tested.	
Hackberry	70	Dug.	(?)	66	Steam pump	80,000	
Peach Springs	920	13	1903	413	do	14,000	Not satisfactory; will be sunk deeper.
Nelson	1,043	13	1902	490		Not tested.	Water struck at 516 feet.

[a] When tested.

DEEP-WELL TEMPERATURES.

Temperature readings taken at two of the deep wells are given in the following table. The results obtained at Yucca are probably more satisfactory than those at Nelson, as conditions were more favorable for satisfactory observation. At Nelson the thermometer was not in the water at the upper horizon tested, while at Yucca it was under water at both horizons. The increase of temperature downward in the Yucca well was 1° F. for 55+ feet. That in the Nelson well was 1° F. for 68+ feet.

Temperatures of water in wells at Yucca and Nelson, Ariz.

Location.	Surface elevation.	Total depth.	Depth to water.	Date of observation.	Surface temperature at time of observation.	Depth at which temperature was taken.	Temperature.
	Feet.	*Feet.*	*Feet.*		°*F.*	*Feet.*	°*F.*
Yucca, Ariz.[a]	1,804	1,004	346	Sept., 1903	98	1,004	90.5
Do	1,804	1,004	346	do	98	455	80.6
Nelson, Ariz.[b]	5,200	1,043	490	do	75	1,040	73.4
Do	5,200	1,043	490	do		200	61.2

[a] General region volcanic. Drilling suspended three months previous to observation.

[b] In limestone region at edge of plateau. No work done on well for several months previous to time of observation.

NOTES ON THE IGNEOUS ROCKS OF WESTERN ARIZONA.[a]

By Albert Johannsen.

PRE-CAMBRIAN CRYSTALLINES.

The oldest of the volcanic rocks in northwestern Arizona are granites (A–6, A–44).[b] According to Lee, they occur below the effusives throughout the entire area, and in the cliffs to the east are overlain by the same series of Cambrian rocks which in the Grand Canyon section is called the Tonto formation. Over the whole area the fact that the granite is an older and not a younger intrusive is clearly indicated by the occurrence of dikes and veins within it which do not extend through the overlying rocks. The upper surface was planed nearly to a base-level and the effusives generally overlie it in horizontal sheets.

Much granite occurs in the area. The rock is red to gray in color, is usually coarsely crystalline, and is much cut by dikes and veins. Here and there in faulted regions, the rock is highly gneissoid, while in other places the mass passes, by easy transitions, from the normal rock to the schistose. The specimens are very similar in mineralogic character, though no thin section of the normal type was examined. Megascopically A–6 is fine and schistose, and consists of black and white bands of feldspar and biotite. A–44 is dark red in color and is very compact. Under the microscope the former is schistose, hypautomorphic-granular, while the latter is similar but without showing schistosity. In both, the minerals are feldspar, less quartz, and still less biotite. Zircon and apatite are accessory. The feldspar is chiefly orthoclase, which is now and then intergrown with plagioclase in the form of microperthite; a little microcline and a little oligoclase or andesine occur. The biotite occurs in shreds and patches (subparallel in A–6) and is in many specimens considerably altered to iron oxide, so that it is black and opaque. Normally the pleochroism of the biotite is $\mathfrak{a}$ = light green and $\mathfrak{b}$ = dark green. Zircon occurs as short, stout, rounded grains, and apatite occurs both in small and thin and in large and stout prisms, the latter being sometimes irregular in form. The accessories occur within both the quartz and the feldspar.

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[a] The specimens here described were collected by Mr. Lee and the geologic relations are given from his observations. The report on the examination of the thin sections was made in 1906.

[b] References are to original specimen numbers; see list, p. —.

Farther to the south, in Williams Canyon, the banding of the underlying rocks becomes much more marked, giving long-drawn-out black and white bands (A-49), for which reason the name of "Banded Canyon" is applied to the gorge through which Williams River flows. Lee describes the rock as apparently continuous with the granitic rocks to the north, although the transition was not followed. Megascopically the rock is aphanitic, black and white banded, the black bands occasionally showing white phenocrysts and rounded inclusions. Under the microscope the texture is markedly schistose. The constituents are irregular rounded grains, very variable in size, of hornblende, orthoclase, some plagioclase, and a little quartz. There is much chlorite, and a little epidote and titanite.

EFFUSIVE ROCKS.

OLDER ANDESITE.

Some time during the Tertiary period, after the Paleozoic and Mesozoic sediments had been removed from the area and the underlying granite deeply eroded, began a period of volcanic activity. The earliest erupted rocks of which traces now remain were andesites, a remnant of which occurs at Black Mesa, north of Boundary Cone (A-11). It here appears to underlie and is cut by dikes of rhyolite (A-12). This is the only area where any eruptive rock is definitely known between the rhyolite and the granite. In several places the andesite (A-40, A-41) rests directly upon the granite, but no rhyolite occurs above it, and consequently the later flow and the intervening rocks may have been eroded. The andesite from Black Mesa is, then, as described above, beneath the rhyolite and is cut by it; and since within the rhyolite flow breccia from various parts of the region andesite fragments occur, it is very probable that this rock is in place and is older than the rhyolite.

Megascopically this andesite (A-11) is dark reddish gray in color and shows numerous white phenocrysts in a fine aphanitic groundmass. Under the microscope the texture is porphyritic and sempatic. The phenocrysts are fairly regular laths, some of which are partially and some completely altered. The partially altered phenocrysts are plagioclase, which still show indistinctly the original twinning, but the extinction angle can not now be determined. They have an index of refraction higher than Canada balsam, and are much altered to calcite, sericite, and kaolin. Besides these, there are fewer chlorite pseudomorphs and still less magnetite. The chlorite pseudomorphs are lath-shaped and are very similar in form and size to the plagioclase laths. None of the original mineral remains, and there is occasionally a center of calcite. Possibly they are pseudomorphs after hornblende. The magnetite occurs in irregular and corroded grains and is usually surrounded by a rusty rim. By incident light the surface appears black and metallic, but with rusty patches, the smaller grains sometimes having the entire surface rusty. The groundmass is anisotropic and full of alteration products, and consists of xenomorphic laths and patches of feldspar, much altered to kaolin, sericite, and chlorite, and of magnetite grains and dust. It has the appearance of having originally contained small lath-shaped feldspars. Whether there was also originally orthoclase is indeterminable. Kaolin occurs as a secondary product in semiopaque patches in the groundmass and in the feldspar phenocrysts.

RHYOLITE SERIES.

Resting upon the andesite at Black Mesa, and in other places directly upon the granite, is a thick series of rhyolites, rhyolite flow breccias, and tuffs, which reach a thickness of 3,000 feet or more. They are all clearly older than some of the andesites (107, A-18) and older than all of the basalts. In the field the general appearance of the rhyolite is white to pink, making a sharp contrast with the underlying granite and the overlying andesites and basalts. Usually the flows are massive, often brecciated, and often very coarse agglomeratic, with angular blocks having a maximum diameter of several feet. In places these included fragments are rounded and the bedding of the tuffs is horizontal. No attempt was made to separate the rhyolite into distinct flows, as might be possible with more detailed study. The areas at which the specimens studied were collected being in many cases far removed from the others, it is impossible to correlate the relative geologic positions.

The rhyolites may be divided into four groups—flow breccia, ash, normal rhyolite, and spherulitic rhyolite.

In general the megascopic appearance of the rhyolite flow breccia is white to pink, with included irregular dark-brown fragments, usually small. Under the microscope the appearance of all (101, A-13, A-19, A-35) is very similar. The rock consists of a glass full of bubbles, often in flow lines and sometimes devitrified. It is full of irregular and broken fragments of orthoclase, quartz, sometimes a little biotite, microcline, apatite, plagioclase, and hornblende, several or all, and usually some iron ore. Some of the specimens are altered and contain, besides iron oxide, much calcite. Besides the mineral fragments contained in the glass, there are irregular dark and altered inclusions of andesite, which clearly indicate that there was a previous eruption of a basic rock. No correlation is possible, however, between these fragments and the single specimen obtained from the flow below the rhyolite at Black Mesa. There may have been, and probably were, volcanic eruptions previous to that of the rhyolite, of which now no trace remains, and the fragments in the rhyolite flow breccia indicate that the andesite was much more extensive than at the present time.

West of Boulder Canyon in Colorado River is a volcanic tuff (A–39). It is gray to pink in color, ashlike, gritty, very friable, and fine grained, and occurs in horizontal beds. Under the microscope it is tuffaceous and is composed chiefly of small angular glass fragments, needle-like and in flakes, and contains a few very small and irregular quartz grains.

Compact normal rhyolite (117, A–7, A–12, A–43) occurs within the rhyolite series, but no attempt was made to find the relationship which may exist between these flows and the sheets of breccia, flow breccia, and so on, in which it occurs. Megascopically these rocks are white or pink and sometimes banded. Under the microscope a glassy flow texture is plainly seen in one of the rocks (A–43), while in others (117, A–7), although now devitrified, the flow texture can be clearly made out. In 117 the original flow lines of the groundmass show in polarized light by the fact that there are larger and more numerous quartz particles along certain lines, while areas between these lines are much finer grained, and very often the centers of these areas are almost entirely isotropic. In the specimen from Black Mesa (A–12), from the region where the andesite (A–11) underlying the rhyolite was obtained, no flow texture can now be made out. It is completely devitrified and is now an aggregate of quartz and feldspar. According to Lee, this rhyolite occurs in dike-like intrusions and in sheets overlying the andesite, a fact which clearly proves the older age of the andesite, provided that the intruded and overlying rocks are both like the specimen (A–12). All of the sections are perpatic. In some, fragments of orthoclase, a little plagioclase, and some quartz occur, and in others the original phenocrysts are much altered. Magnetite and zircon are accessory, and calcite and zeolites secondary minerals. Chlorite, from an original femic mineral, occurs in 117.

Two of the rhyolite specimens are spherulitic (A–1, A–8). Megascopically these specimens are pink, spherulitic, and full of large irregular cavities, occasionally filled with quartz crystals. Under the microscope the rock shows very few phenocrysts of orthoclase, plagioclase, and biotite, and rather rare magnetite crystals in a spherulitic groundmass. In one specimen (A–8) the entire rock is filled with trichites, generally in hairlike bunches. Sometimes margarites occur—that is, hairlike strings of globules; and in places microlites appear in schools. In the specimen from Wickenburg (A–1) there is, in the groundmass, besides the spherulites, a quartz-orthoclase aggregate in finger-like interlocking particles. The rock is rather dark with feritic material, and there is considerable kaolin and other alteration products. In the rays of the spherulites there is often a deposit of red hematite or limonite, and cubes of what may have been magnetite show a slight red edge in transmitted light, as though altered to limonite.

YOUNGER ANDESITES.

Definitely in place in a number of localities above the rhyolite is an andesite (107, A–18). This is much more limited in extent than the earlier flow. A number of other andesites which occur in the area either rest directly upon the granite (A–40, A–41) or are in masses isolated from the other effusives, so that no relationship is seen (112, A–2, A–42); they may belong either to the upper flow, the underlying rhyolite having been eroded, or to the earlier flow. In the field all of the andesites are of a dark-red to brown color, are often vesicular, and are often very hard to distinguish from the overlying olivine basalts.

The two specimens (107, A–18) from above the rhyolite are dark reddish black in color and are vesicular, with more phenocrysts in A-18 than in 107. Under the microscope the two rocks are very similar in appearance. Both of them are porphyritic-intersertal in texture and contain more phenocrysts than groundmass. The phenocrysts occur in two generations and consist of plagioclase (andesine to labradorite), augite, and magnetite. The larger plagioclase crystals occur as irregular fragments, often zonal, while the smaller occur in perfect laths. There is much less augite than plagioclase. This also occurs in two generations, and in each case is less in amount than the corresponding generation of plagioclase. Two generations of magnetite, less in amount than the augite, occur in quadratic and irregular crystals and grains. Of these the larger crystals are less in amount and the grains are smaller than the second generation of augite, and the small crystals are very small and are scattered through the groundmass in isometric crystals. They occasionally occur in the augite, but very rarely in the feldspar. The groundmass in both specimens is isotropic and consists of brown glass full of magnetite—so much in A–18 that it is nearly opaque.

Specimens A–40 and A–41, from sheets in the walls of Black Canyon, are augite andesite; possibly the latter at one time contained olivine; if so, it was an olivine basalt. Megascopically they are medium dark red-brown in color, with more or less black and white phenocrysts in an aphanitic groundmass. Under the microscope they are porphyritic and sempatic. The phenocrysts of 40 consist of broad, irregular laths, and the groundmass is apparently a devitrified glass, full of dust and grains of magnetite and hematite. Specimen 41 has phenocrysts of plagioclase, somewhat greater in amount than augite and much greater than some red-brown pseudomorphs which may be altered biotite or olivine. The groundmass in this specimen is in laths and irregular patches, much of which is definitely plagioclase. Besides the feldspar, much black and red iron oxide and shreds of augite and dark altered biotite (?) occur.

A–42 is a biotite-augite andesite from a sheet forming Eagle Rock, near Little Round Island, and is similar in character to the two preceding. The phenocrysts, less in amount than the groundmass, are, in the order of their importance, plagioclase, biotite, diopside, and magnetite. The plagioclase is andesine to labradorite. The biotite has a peculiar deep red-brown color, is pleochroic with 𝔟=brownish red and 𝔞=greenish yellow, and has much the appearance of basaltic hornblende. It has, however, parallel extinction, gives a uniaxial interference figure, shows parallel cleavage in laths, has the "bird's-eye maple" surface, and is optically negative. It always has a dark rim of magnetite. The pyroxene is pale green in color, is nonpleochroic, has an extinction of about 40°, and has good cleavage—parallel in laths and at right angles in basal sections. It is diopside. Both the plagioclase and the pyroxene are much altered to calcite. The ground mass is yellowish to red, cloudy, and apparently partially devitrified glass full of red ore dust. Most of the anisotropic part of the groundmass is spherulitic or contains innumerable microlites.

South of Seligman there is a hypersthene andesite (113). This is from the lower of two flows, the upper of which is darker and may be basalt, though no specimen was examined. Megascopically 113 is a dark-gray rock with white patches and occasional calcite fillings in cavities. Microscopically the texture is porphyritic and dopatic. The phenocrysts are either thin or broad laths, and the groundmass is hypautomorphic. The phenocrysts, in the order of their abundance, are plagioclase, augite, and hypersthene. The feldspar occurs in both large and small laths. The stout crystals are not twinned and are always zonal; the narrow crystals are usually twinned and give an extinction between 20° and 25°, or that of andesine. In the zonal feldspars the index of refraction at the center is higher than at the rims; the interference figures are positive, and show a comparatively small value for 2E. This excludes all the feldspars but andesine and labradorite. Since the rims have a lower index but are still positive in character, it shows that the feldspar is either labradorite or andesine or both, and that the interior is more basic than the exterior. The femic minerals consist of very irregular grains of a greenish pyroxene with a high extinction angle—augite; and another pyroxene occurring in elongated prisms with longitudinal cleavage, having parallel extinction, showing high interference colors, optically negative, and slightly pleochroic in pink and green tones—hypersthene. Magnetite occurs in grains which, in size, grade into the groundmass. There is no definite line, and it is in such irregular grains that it may be included with either the phenocrysts or the groundmass. Exclusive of the femic minerals, the groundmass is made up of xenomorphic areas and laths of feldspar which are probably of the same kind as the large phenocrysts. The xenomorphic feldspar has an index of refraction greater than Canada balsam and is consequently plagioclase, but the areas are so small that the kind is indeterminable. Besides the feldspar there is an isotropic substance which occurs in very small anhedrons and which may be glass or a zeolite. The groundmass is full of magnetite dust and there is an alteration product in the cleavage cracks of some of the feldspars which is anisotropic and has an index of refraction less than Canada balsam. It is a zeolite.

Twenty-five miles west of Congress Junction there occurs a coarse breccia formed of large angular blocks cemented with red material. Megascopically the specimen (A–2) has a red compact groundmass, and there are phenocrysts of hornblende forming about one-eighth of the mass. Microscopically the texture is porphyritic and perpatic. The phenocrysts are hornblende, much less plagioclase, and still less biotite. The hornblende is very peculiar in several ways. It has a very low extinction angle, generally appearing as parallel, the largest found being only 3¾°—that is, c: $\mathfrak{c}$ is circa 4°. The pleochroism is also peculiar. For $\mathfrak{a}$ it is a greenish yellow, while for $\mathfrak{c}$ it is a deep red-brown. Absorption $\mathfrak{c}>\mathfrak{a}$. The elongation is parallel to $\mathfrak{c}$, and therefore it is positive, while the optical character of the mineral is negative. Surrounding the mineral there is always a dark rim of iron oxide. This is usually black, but occasionally it shows a red tone. The cleavage is good, parallel to ċ in lath-shaped sections, and in basal sections the usual amphibole cleavage. The mineral is basaltic hornblende. The feldspar is generally zonal and is positive in character. It is between andesine and labradorite. Actually the amount of plagioclase that occurs is much less than the amount of hornblende, but the phenocrysts of feldspar have either weathered out or been ground out in preparing the thin section. Apparently they were originally much more numerous and both longer and broader than the hornblende. Biotite occurs in a very few long, thin flakes. It has dark rims, and magnetite is included along the cleavage lines. Pleochroism is brownish to greenish. Magnetite occurs in irregular grains. The groundmass consists chiefly of laths of plagioclase, which have an extinction angle of 30° and are consequently labradorite. Between the feldspar laths there is a much iron-stained substance which is probably glass. Iron oxide occurs in the form of very fine dust and in patches, producing the red color of the rock.

OLIVINE BASALTS.

Resting upon the andesite, upon the rhyolite, or even upon the granite, and also upon and within Quaternary gravels, depending upon the amount of erosion that has taken place, is a series of olivine basalts—the youngest lava in the region. There are at least three flows of this, but it is impossible, from the amount of field work done, to correlate the different sheets in different parts of the area. Five or six varieties can be distinguished under the microscope, but they may be but different phases of the same rock, a greater or less development of olivine or a coarser or finer groundmass forming the various types. This difference in appearance may be seen even in two sections (as 110, 111) which have been collected near together from undoubtedly the same flow and which show different characters. Five types may be distinguished, according to the fineness of the groundmass: (A) 110, 111, 3, 45; (B) 15, 16, 24, 25, 27; (C) 37, 46; (D) 22, 23; (E) 30, 34.

Occasionally the field relation can be seen; thus, 24 is from a sheet overlying 25; 15 is from a sheet intruded into the rhyolite and lifting it; and 16 is from a sheet above the rhyolite.

In the field the general appearance of the basalt is black or very dark red. In general it is darker in color than the underlying andesite and is often vesicular and ropy. Where it rests upon the rhyolite it forms sharp cliffs. In many places it forms flows in erosion valleys, and though actually lower in position, is higher geologically.

Megascopically the hand specimens are compact and vary in color from black through dark gray to dark brownish red. Occasionally there is a somewhat banded arrangement—that is, alternating bands of a lighter color. Under the microscope the texture of all the specimens is porphyritic, with a groundmass generally trachytic and with the small plagioclase laths in subparallel position. In general the phenocrysts of the rock are olivine, or, when other minerals occur, they are greatly in the minority. In four specimens, however (22, 23, 45, 46), the phenocrysts are chiefly plagioclase.

In specimens 22 and A–23 the plagioclase phenocrysts are greatly in excess of the olivine, and the latter are much in excess of the augite. The groundmass is much coarser than A–45 and consists of plagioclase laths and areas, less augite grains, and still less magnetite. The feldspar is labradorite. Olivine is very much altered to a red-brown mineral which may be iddingsite or an iron-stained serpentine. Some of the olivine is fresh and shows simply an altered rim or altered center.

A–45 is perpatic, has a much finer groundmass than either A–22 or A–23, and does not contain prominent augite grains in the groundmass. The constituents, in the order of their abundance, are plagioclase, augite, olivine, and magnetite. The feldspar is labradorite or andesine. The olivine occurs in doubly terminated crystals, only slightly altered.

A-46 is very similar to A-23, except that the difference between the size of the grains in the groundmass and the phenocrysts is not so great.

Specimens 110, 111, and A-3 are similar to A-45, in having a very fine groundmass. The phenocrysts of 110 and 111 are augite and biotite in about equal amounts, and less of a completely altered red-brown mineral which may have been olivine. The biotite and augite are usually altered in part also, and are surrounded by black rims. The groundmass consists of lime-soda feldspar laths in subparallel position in swirling eddies—a trachytic texture. There are also a few small irregular patches in the groundmass which have an index of refraction less than Canada balsam and are faintly anisotropic. They may be analcite, but are too small to determine. Calcite occurs as a secondary product, and magnetite occurs in a few large crystals as well as in small grains in the groundmass.

In A-3 there are more augite phenocrysts than olivine. The latter is altered, completely or in cracks, to a red-brown mineral, which has an index of refraction much less than that of the olivine and is fibrous. It appears to be iron-stained serpentine. Magnetite occurs within the olivine in rather large grains and crystals. The groundmass consists of laths of labradorite in broad flow lines swirling around the olivine phenocrysts. Almost invariably they are twinned according to the albite law, and show an extinction angle in the neighborhood of 30°. Between the feldspar laths is much augite, pale green in color, and occurring in irregular grains, never in well-formed crystals or laths. Somewhat less in amount is magnetite, which occurs in cubical and irregular sections. Less in amount than the magnetite and, like it and the augite, occurring in irregular grains between the feldspar laths, is a reddish-brown mineral which has an index of refraction apparently greater than the augite. The grains are small and irregular, so that the determination is impossible. It appears to be partially altered olivine.

Somewhat coarser in texture under the microscope than the above are A-15, A-16, A-24, A-25, A-27, A-37. Of these, A-15 and A-16 have phenocrysts of olivine, augite, and plagioclase, with hornblende and biotite also in A-16. The olivine phenocrysts are generally entirely altered to a brownish-red serpentine and are usually ground out in the centers in preparing the section. The groundmass of A-15 is a dark glass full of small laths of plagioclase, laths of augite, and grains of red iron oxide, while A-16 has a groundmass of dark glass full of innumerable small feldspar laths and microlites and magnetite dust.

A-24, A-25, A-27, and A-37 are very similar in appearance. The texture of all of them is porphyritic, with phenocrysts of olivine and a groundmass made up of laths of feldspar and grains of augite and magnetite and glass full of magnetite dust. The amount of glass is small and fills spaces between the plagioclases, but these spaces are very few and hardly show in the thickness of the section. The olivine phenocrysts are rather fresh, being generally altered only around the rims. Secondary calcite is common.

A-37 has more plagioclase than A-24 and the olivine is entirely altered to a dirty brownish-black substance.

A-30 and A-34 are porphyritic, with irregular rounded to angular crystals of olivine which are perfectly fresh. Some magnetite may be classed with the phenocrysts. The groundmass consists of long, narrow laths of labradorite with extinction angles of from 32° to 35°, and a less amount of a purplish, very slightly pleochroic augite, which fills the interspaces. The augite is not in typical ophitic form, but in irregular laths which fill the interstices. Generally it is very fresh, although there are patches of serpentine in the groundmass, some of which is definitely derived from olivine. Within the augite there is a great deal of magnetite in strings and in skeleton crystals, in beautiful branching forms.

DIKE ROCKS.

OLIVINE DIABASE.

Cutting the rhyolite at the eastern edge of Black Mesa, in Gold Roads Pass at Mud Spring, is a large dike, some 25 feet in thickness, of olivine diabase (A-14), apparently connected with a dark sheet which overlies the rhyolite. Megascopically the rock is dark in color and is rather coarsely granular. Under the microscope it has a typical ophitic texture and there is more feldspar than augite. The feldspar occurs in twinned laths with a maximum extinction angle of 31°, and is labradorite. It is very fresh, although occasionally it contains serpentine in cleavage cracks. Fresh augite in less amount than the plagioclase fills the interspaces between the feldspar laths. It is pale purple in color, and is nonpleochroic or very slightly pleochroic. It contains a small amount of iron oxide in extremely fine particles. Olivine, less in amount than the augite, occurs in irregular rounded grains, mostly small, though some are large. Some of the olivine is altered to serpentine, chlorite, and red iron oxide around the edges and in cracks. Magnetite occurs in still less amount and in irregular grains.

RHYOLITE PORPHYRY.

At the base of Boundary Cone is a plug, or dike from a plug, of rhyolite porphyry (A-10). Megascopically it is a pink, fine-grained rock, with quartz and feldspar phenocrysts. Under the microscope the texture is porphyritic and dopatic. The phenocrysts are large, occasionally somewhat corroded, and the groundmass is xenomorphic-holocrystalline. The phenocrysts are orthoclase, greater in amount than quartz, and much greater than acid plagioclase. The plagioclase occurs in but few crystals; it has, in part at least, an index of refraction less than Canada balsam, and is probably all albite. The groundmass is a quartz-feldspar aggregate with much hematite. Secondary kaolin and sericite are derived from the feldspar, and the red iron oxide perhaps from magnetite.

ROCK SAMPLES FROM NORTHWESTERN ARIZONA.

Following is a list of rock samples collected in northwestern Arizona with the original specimen numbers:

A-6. Granitic gneiss from south end of Hualpai Mountains.
A-10. Granite porphyry from base of Boundary Cone west of Black Mesa.
A-44. Biotite granite from mouth of Williams River.
A-49. Granite gneiss from Williams Canyon.
101. Rhyolite flow breccia from Lost Basin, about 5 miles south of Colorado River, in a depression of older crystalline rock.
A-35. Rhyolite breccia from Temple Bar.
A-7. Rhyolite from southern end of Black Mesa, at base of cliffs.
A-39. Rhyolitic tuff from Colorado River west of Boulder Canyon.
A-12. Rhyolite from Black Mesa, at Gold Roads.
A-13. Rhyolitic tuff from Black Mesa, in pass east of Gold Roads.
A-19. Rhyolitic tuff from Black Mesa, at summit of Union Pass.
A-43. Rhyolitic tuff from bluffs of Colorado River in Chemehuevis Valley.
A-2. Hornblende andesite from southern end of Aquarius Mountains, a few miles north of Date Creek.
A-11. Andesite from Black Mesa, north of Boundary Cone.
A-40. Andesite from north end of Black Canyon.
A-41. Andesite from south end of Black Canyon.
A-42. Andesite from Eagle Rock, near Little Round Island.
107. Andesite from coyote holes northwest of Kingman, at western edge of mesa.
A-18. Andesite from a sheet above the rhyolite 2 miles northwest of Kingman.
110, 111. Basalt from a flow sheet 300 feet thick resting on top of 400 feet of varicolored ash and breccia at mouth of White Cliff Creek.
112. Andesite resting on granite at top of Cottonwood Cliffs near mouth of Cottonwood Creek, 1,200 feet above Nos. 110 and 111.
A-3. Olivine basalt from a sheet in the detrital beds of Santa Maria Canyon, near mouth of Big Sandy Wash.
A-15. Basalt intruded into the rhyolite 1 mile west of Kingman.
A-16. Basalt from a flow sheet above the rhyolite 1 mile west of Kingman.
A-27. Olivine basalt from a sheet above the andesite near Kingman.
A-30. Olivine basalt from a columnar sheet resting on the Temple Bar conglomerate north of Colorado River in Grand Wash.
A-34. Olivine basalt from a flow sheet within the Temple Bar conglomerate near Greggs Ferry.

A-14. Olivine diabase from the eastern edge of Black Mesa, at meadow spring in Gold Roads Pass; dike cutting the rhyolite.

A-22. Olivine basalt from Mud Spring at eastern edge of Black Mesa.

A-23. Olivine basalt from north end of Cerbat Mountains.

A-24. Olivine basalt from a sheet resting upon granite east of Cerbat Mountains.

A-25. Olivine basalt from a sheet resting above A-24.

A-45. Basalt from a sheet 800 feet thick covering the Temple Bar conglomerate in Williams Canyon.

A-46. Olivine basalt near Planet, in Williams Canyon.

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O

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OF THE

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J. S. DILLER

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GEOLOGY OF THE TAYLORSVILLE REGION OF CALIFORNIA.

By J. S. Diller.

INTRODUCTION.

LOCATION AND EXTENT.

The Taylorsville region is a triangular area on the northern end of the Sierra Nevada in California. It lies in the northeastern angle between the fortieth parallel and the one hundred and twenty-first meridian, and embraces the northeastern part of Plumas County and the adjacent portion of Lassen County, comprising about 750 square miles. The greater portion of the population is in Indian Valley, Genesee Valley, and North Arm. The town of Taylorsville, from which the whole region is here named, is approximately in its center.

OUTLINE OF THE GEOGRAPHY AND GEOLOGY OF THE REGION.

Northern California belongs to five topographic provinces, consisting of three mountain ranges—the Coast, Cascade, and Sierra Nevada—and two valleys—the Sacramento and the valley of the interior, which forms a part of the Great Basin. The Coast Range includes the Klamath Mountains, which occupy the northwest corner of the State. Lassen Peak, the southern end of the Cascade Range, lies between the Klamath Mountains and the Sierra Nevada, as shown in Pl. I, giving them apparent continuity, but in reality separating them, for the Cascade Range is wholly of volcanic origin and presents marked contrast to the Sierra Nevada and Klamath Mountains. The Taylorsville region belongs to the Sierra Nevada, but is bordered on the north by the Lassen Peak portion of the Cascade Range and on the east by the Great Basin.

The main body of the Sierra Nevada has but one crest, with a long, gentle slope southwestward to the Sacramento Valley and a short, steep slope northeastward to the Great Basin. It appears as a great block of the earth's crust tilted toward the southwest. The northern end of the range, beyond Lake Tahoe, has three crests, those of Clermont Hill ridge, Grizzly Mountains, and Diamond Mountain, and each crest has a valley at its northeast base. The western crest, the Clermont, is continuous with the main crest of the range north of Lake Tahoe. American and Mohawk valleys lie to the northeast. The other two are crests of blocks that have been added in the Taylorsville region on the northeast of the main block, as shown in fig. 1, causing the eastern face of the range to advance in that direction nearly to Honey Lake.

The geology of the Sierra Nevada is complex. Although the range is the result of an uplift that occurred in comparatively recent geologic time, the material of which it is composed involves a long and varied succession of deposits of sedimentary and igneous rocks, extending from early Paleozoic to the close of Jurassic time. During that long period the Sierra Nevada region was beneath the sea, receiving sediments from a land area along the eastern border in Nevada. About the close of the Paleozoic era the rocks were compressed and folded, and were intruded to some extent by igneous rocks, so that the Mesozoic sediments, which are of much less bulk than the Paleozoic, were deposited upon the latter unconformably. At the close of the Jurassic the Sierra region was again greatly compressed and uplifted, forming a prominent mountain range. The rocks were folded and rendered schistose or platy in connection with the intrusion of great masses of granitic and other igneous rocks.

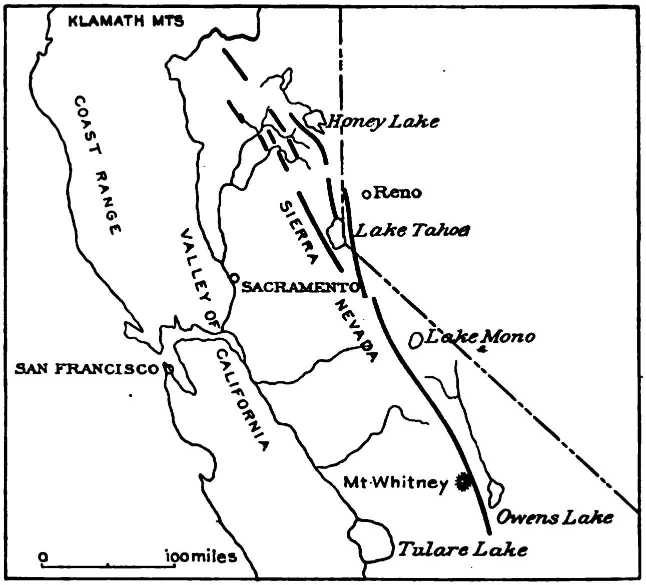

FIG. 1.—Faults limiting the Sierra Nevada on the northeast. Heavy black lines indicate position of faults.

Long-continued erosion during the Cretaceous and Tertiary period, coupled with minor oscillations of the land, reduced the Sierra Nevada to a region of low relief, when streams flowed in broad, shallow valleys, in which the earlier auriferous gravels accumulated. Among the finer gravel beds are fossil leaves, including several varieties of figs, oaks, and other plants, which indicate that the flora resembled that of a low coastal country like Florida. Near the low crest volcanic vents poured forth streams of lava, which followed the watercourses, covered the auriferous gravels, and displaced the streams. With this volcanic activity and stream displacement came differential uplift, which greatly increased the stream grades and caused them to cut the deep canyons in which they now flow down the western slope of the Sierra, leaving the auriferous gravels of their old beds on the divides far above.

TOPOGRAPHY.

RELIEF.

As may be seen on the general map of the Honey Lake and Taylorsville regions (Pl. II), the relief consists of two lines of crests and of two valleys, all having a northwest-southeast trend, parallel to the general course of the Sierra Nevada. On the one hand lies the valley of Honey Lake and Susan Creek, and on the other the belt of valleys stretching from Mountain Meadows to Genesee. Between these lines of valleys lies the Diamond Mountain block, whose crest line is prominent from McKesick Peak to Diamond Mountain. The crests of Grizzly Mountains and Keddie Ridge belong to the Grizzly topographic block, and both blocks lie just northeast of the main crest of the Sierra Nevada at its northern end.

DIAMOND MOUNTAIN BLOCK.

The Diamond Mountain block, extending from Honey Lake southwestward to Grizzly Mountains, has a width of over 20 miles and a length north of the fortieth parallel of over 50 miles. Its crest line lies close along its northeastern side, from McKesick Peak to Diamond Mountain, presenting a bold escarpment over 2,000 feet high in the short steep slope to Honey Lake. The slope on the opposite side, to the southwest, is long and gentle, having the appearance of a plateau. Beyond Lone Rock the block gradually narrows, loses its relative elevation, and dies out in a plain before reaching the head of Susan Creek. This disappearance, however, is due more to the general rise of the adjoining county toward Lassen Peak, as shown by the drainage lines, than to any decrease in the general elevation of the Diamond Mountain crest, for it maintains its elevation of 7,000 feet near the end. The prominent features of the Diamond Mountain block are the escarpment, the plateau slope, and the valleys along its western border.

THE ESCARPMENT.

The escarpment although bold is not generally a cliff, and at two points in a distance of 40 miles between Willow Ranch and Gold Run it is traversed by wagon roads. It is remarkably regular with few prominent spurs and reentrants and gives rise to no considerable stream. Gold Run marks its northern terminus. Beyond that point the eastern slope is as long as the western and the divide becomes symmetrical.

THE PLATEAU SLOPE.

The general features of the plateau are best displayed about the heads of Squaw, Last Chance, and Indian creeks, where the general altitude is about 6,000 feet, rising to 7,000 feet at a number of points along the crest. One of the best general views of the plateau is from the slope of Kettle Rock Mountain looking southeast. Although there is a decided community of altitude suggesting an approximation to a common level, it is far from being a complete plain, and yet it may well be called a peneplain. Kettle Rock Mountain is the greatest elevation in it, rising above the general level nearly 2,000 feet, but for the most part by such gentle slopes that the difference of altitude is not out of harmony with the peneplain. The gentle summit slopes continue northwest into Lassen County beyond the limit of the escarpment, where the great difference between the two slopes of the block disappear.

The upper courses of the streams are in broad, shallow valleys, but as they approach the middle portion of the block they cut deeper and deeper until they flow in canyons. Lights Canyon, Cooks Canyon, and the canyons of Indian and Squaw creeks above Flournoy are examples, and they all open into broad alluvial valleys below.

VALLEYS OF THE SOUTHWESTERN BORDER OF THE DIAMOND MOUNTAIN BLOCK.

Genesee Valley.—The general trend of the valley belt along the border of the Diamond Mountain block is northwest and southeast from Genesee Valley to Mountain Meadows. Genesee Valley is at its southeastern extremity. It has a breadth of one-third to three-fourths of a mile, and a length of nearly 6 miles northeast and southwest directly across the general trend of the valley belt. It is a flat alluvial plain on both sides of Indian Creek, with irregular border from jutting spurs and lateral branches running up Red Clover, Wards, Hosselkus, and Little Grizzly creeks. None of it is too swampy for use but some is too dry without irrigation. There is a large ranch at each end and four smaller ones between.

Indian Valley.—Indian Valley is much larger than Genesee, and less regular. The main part extends northwest from Taylorsville to Greenville about 9 miles with an average width of over a mile. At right angles to this is North Arm, which extends up Lights and Cooks creeks for nearly 5 miles with a width ranging from a quarter to nearly a mile and widening to the north. Indian Valley proper between Taylorsville and Crescent Mills is nearly all arable, but the adjoining portions of North Arm and Greenville Arm, except the borders, are swampy, although the other portions of both arms have large and excellent farms.

A feature of importance in the main body of the valley 2½ miles northwest of Taylorsville is the Mounds, two dome-shaped hills, which stand out in the valley plain. One rises 100 feet and the other over 200 feet above the surrounding plain. There is a third opposite the entrance of North Arm, a mile north of Taylorsville, but it rises less than 50 feet above the valley plain.

Mountain Meadows.—Mountain Meadows are triangular in shape, widening to the northwest, where they merge into the plains bordering the volcanoes about Lassen Peak. On the southwest they are sharply limited by the steep slopes of Keddie Ridge, but along the eastern side its margin is somewhat less definite on the gentle slope of the Diamond Mountain block. The valley is dry to a large extent except in the northwestern part, which is traversed by Fredonia Creek, from the pass of the same name. Mountain Meadows, having a general elevation of 4,800 feet, is about 1,300 feet above the general level of Indian Valley, from which it is separated by a low divide at the head of Cooks Canyon.

Jura Valley.—Between Mountain Meadows and North Arm of Indian Valley there is a broad gap crossing a flat ridge, and the same is true between North Arm and Genesee Valley, where the gap is a broad depression in the ridge crest that joins Mount Jura to Kettle Rock Mountain. These two gaps belong to the plateau or peneplain features of the Diamond Mountain block. A line joining them lies in the axis of the valley belt, and these gaps are remnants of an old valley along that line nearly 2,000 feet above the present valleys of North Arm and Genesee. This old valley lies on the east slope of Mount Jura, hence the name Jura Valley. It was once occupied by Jura River.

GRIZZLY MOUNTAIN BLOCK.

The Grizzly Mountain block, which lies between the Diamond Mountain block and the main crest of the Sierras and extends from Grizzly Mountains and Keddie Ridge to American Valley, forms only a small part of the Taylorsville region. The Grizzly Mountain block is smaller and much less regular than the Diamond Mountain block.

CREST LINE AND ESCARPMENT.

The crest line and escarpment are well marked in Grizzly Mountains, which present a steep slope of over 3,000 feet to the west end of Genesee Valley. Toward the northwest the crest line sinks and curves, running to Taylorsville, where it disappears in the valley, but rises again in Keddie Ridge and curves back to its northwest course. A small notch is cut by Montgomery Creek across the north end of Grizzly Mountains, but the broad gap in the crest occupied by Indian Valley is more than a mile in width. Keddie Ridge, which carries the crest beyond Indian Valley, is about 14 miles in length and ends in plains at both extremities.

SOUTHWEST SLOPE.

The southwest slope of Grizzly Mountains is larger and gentler than the slope in the opposite direction, but is not so gentle as the corresponding slope of the Diamond Mountain block and retains but few, if any, definite traces of an inclined peneplain. South of the fortieth parallel the crest continues for 15 miles to Grizzly Peak, and a parallel valley follows the western edge of the block all the way from Mohawk to American Valley. About Crescent Mills and Greenville the western slope is broken down to the level of Indian Valley, which crosses the main crest, giving especial prominence to the escarpment of Arlington Heights and Houghs Peak, which form a second crest. Beyond Round Valley Reservoir the slope of the Grizzly Mountain block is better preserved in the northwestern inclination of the divide between Indian Creek and North Fork of Feather River.

DRAINAGE.

The Taylorsville region belongs to two drainage systems, the Great Basin and the Sacramento River, and the water parting is along the eastern crest of the Diamond Mountain block. That which belongs to the Great Basin finds its way into Susan Creek or upper Long Valley, and finally into Honey Lake, which has no outlet, and lies at the very base of the Diamond Mountain escarpment, receiving nearly all its water from the streams flowing southeast or northwest parallel to the escarpment.

All the drainage west of the Diamond Mountain crest goes into the North Fork of Feather River. The drainage from Mountain Meadows passes around the northern end of Keddie Ridge of the Grizzly Mountain block into Big Meadows, where it enters North Fork of Feather River.

The part of the Diamond Mountain block within Plumas County is drained by Indian Creek, whose branches from Cooks Canyon to Last Chance Creek, inclusive, head along the crest forming the county line, while Squaw Creek drains Red Clover Valley, which heads against the great Sierra Valley. The Diamond Mountain and Grizzly blocks, which combine south of the fortieth parallel and merge into the broad summit, Sierra Valley, are completely drained by the tributaries of Feather River. North Fork drains all that part lying north of the fortieth parallel in the Taylorsville region except a small

SILURIAN.

GRIZZLY FORMATION.

Lithologic character.—The Grizzly formation is a gray, well-defined but thin-bedded quartzite overlain by lentils of limestone and interstratified with shaly, often siliceous slate (argillite) having irregular cleavage. The beds of quartzite range from 5 to about 20 feet in thickness and run out into shale in a short distance. The shale beds are generally thicker than the quartzite. They are for the most part greenish gray to drab, but sometimes black and more or less flinty, but not much altered. The lighter colored shales are often sandy and constitute the prevailing portion of the formation, although beds of well-marked quartzite are usually present and frequently predominate. The coarser beds of quartzite contain small pebbles of rhyolite, rarely as large as a pea. These beds, with occasional little pebbles, are near the base of the formation and have a thickness of about 200 feet. The black shale, sometimes flinty, is full of traces of organisms, which E. O. Ulrich has identified as sponge spicules. On the eastern slope of Grizzly Mountains, near the northern end, quartzite prevails immediately beneath a lentil of limestone, but north of Montgomery Creek shales occupy the corresponding position, as shown in fig. 2. The section as shown in this figure, however, does not continue below the tunnel, and therefore does not disclose the coarser beds lying at the bottom of the Grizzly quartzite horizon.

Areal distribution and thickness.—The quartzite of the Grizzly formation occupies a narrow belt near the crest and parallel to it on the northeast slope of Grizzly Mountains. It extends from Taylorsville southeast across Montgomery Creek and along the slope, where it is cut into patches by pyroxenite and meta-andesite, reaching the fortieth parallel in the glaciated ravine half a mile northeast of Tower Rock. At this point the belt of Grizzly quartzite abruptly narrows and vanishes along the border of the ancient rhyolite and the overlapping basaltic volcanics. Immediately south of the fortieth parallel this rock has been sought for by H. W. Turner in the Downieville quadrangle, but its presence could not be demonstrated. The length of the belt of Grizzly quartzite from Taylorsville to the fortieth parallel is about 6 miles, and its exposure is not known to extend beyond in either direction. A portion of the area mapped as Grizzly formation about the mouth of Montgomery Creek, embracing a tract one-fourth of a mile in width and nearly 2½ miles in length along the left bank of Indian Creek, is referred to this horizon with doubt. Although quartzite and siliceous slates occur there the prevailing rock is thin-bedded sandstone instead of quartzite. Locally the sandstone contains pebbles, but it is generally fine

System.	
Quaternary	Al
Tertiary	A A A B A
Early Cretaceous or late Jurassic.	I
Jurassic	F H B M Th F H T
Triassic	S H
Carboniferous	R R C
Devonian?	T
Silurian	M G M

grained. At one point it shows decided spheroidal weathering and resembles certain beds in the Arlington formation, from which, however, it differs decidedly in mineral composition. The spheroidal sandstone in question near Montgomery Creek contains quartz grains whose bipyramidal form indicates that they were most likely derived from the underlying metarhyolite.

There are two small outliers of the Grizzly formation near the fortieth parallel a mile northeast of Tower Rock. In both cases they are masses of much crumpled black, flinty slates from 25 to 40 feet in thickness associated with the ancient rhyolite into which they have been folded or faulted.

The thickness of the Grizzly formation, where measured near the northern end of Grizzly Mountains, is about 400 feet, and this is near the maximum. The strike of the formation is northwest and southeast parallel to its outcrop, and its dip is southwest into Grizzly Mountains between Taylorsville slates which lie upon it and a mass of ancient rhyolite on which it rests.

Relation to adjoining formations.—The contact of the Grizzly formation and the underlying rhyolite is more or less irregular and difficult to follow, but the irregularities are those of the original lava surface accented by much subsequent folding and displacement. This relation may be plainly seen on the lower slope of Grizzly Mountains opposite Huntingtons, where a tongue of sandstone is folded into the metarhyolite, whose fluidal structure on both sides is parallel to the well-marked bedding in the sandstone. That the rhyolite is older than the overlying quartzite is evidenced by the fact that small pebbles of the rhyolite occur in the quartzite. Although not abundant nor large they are common and characteristic, and confirm the view that the quartzite was deposited on the rhyolite.

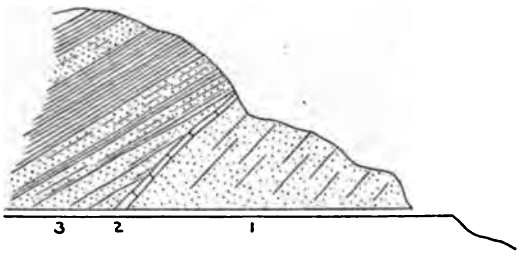

FIG. 2.—Tunnel section of Grizzly formation (1), Montgomery limestone (2), and Taylorsville formation (3).

Above the quartzite comes the Montgomery limestone, and the two are conformable, as shown in the small section (fig. 2) along the tunnel on the east slope near the crest of the ridge 2 miles south of Taylorsville. The fine conglomerates, sandstones, and slates of the Taylorsville formation overlie the limestone and quartzite apparently with unconformity.

Fossils and age.—The only fossils discovered in the Grizzly formation, outside of the limestone lentils, are sponge spicules found in thin sections of the black shaly portions. They indicate a marine origin for the sediments, but afford no definite information as to its age. There can be no reasonable doubt, however, that it is older than the lentils of limestone described below.

MONTGOMERY LIMESTONE.

Lithologic character.—This limestone was called the Montgomery[a] limestone from its occurrence on that creek, 2⅓ miles south of Taylorsville. The limestone is light to dark bluish gray and cleaves into plates. It has occasional knots or benches of black chert and some of the few fossils are replaced by it. The form of the limestone is lenticular, and the largest lentil has a thickness of 60 feet, with a length of about 200 feet. The strike is approximately parallel to the crest of Grizzly Mountains, and the dip is to the southwest.

Areal distribution.—Five of these limestone lentils have been found at intervals along the western border of the quartzite between Taylorsville and the fortieth parallel. The first occurs at the tunnel shown in fig. 2, where it has a thickness of 20 feet. The second is on the south bank of Montgomery Creek, forming prominent cliffs at an altitude of about 4,000 feet. The third and largest lentil, 60 feet in thickness, is on the crest of Grizzly Mountains, at their northern end, having an altitude of nearly 7,000 feet. This is by far the most important lentil, on account of the fossils it contains. Two miles farther southeast, in the cliff overlooking the Devils Punch Bowl, is a lentil of limestone about 15 feet in thickness and exposed for 60 feet. No fossils were found here, but the limestone is in the same horizon as that containing the fossils at the northern end of Grizzly Mountains. The last and smallest lens of limestone occurs in the slates near the top of a flat spur one-eighth of a mile north of the fortieth parallel. It is only about 4 inches in diameter. South of the fortieth parallel Turner has not been able to find any exposed lentils of the limestone, nor have any been found by the writer north of Taylorsville. Limestone has been reported from a well on one of the mounds of Indian Valley, but the determination is a matter of doubt. The extreme limits of the exposed lenses are about 12 miles apart.

Fossils and age.—Fossils were discovered in this limestone on Montgomery Creek and the crest of Grizzly Mountains by Cooper Curtice in 1890. A few fossils were added by others to those collected by Curtice, and among them C. D. Walcott identified the following forms:

Crinoid stems.
Stromatopora sp. (?).
Zaphrentis.
Syringopora (like S. serpens).
Heliolites.
Halysites catenulatus.
Orthis (of the type of O. flabellum).
Ormoceras (cf. siphuncles).

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[a] Bull. Geol. Soc. America, vol. 3, 1892, pp. 372 and 376.

According to Walcott, these fossils are undoubtedly Silurian and "represent the Niagara horizon of the Mississippi Valley and Appalachian provinces."

Last summer the locality was visited and a collection made by James Storrs. It was referred to E. O. Ulrich, who reports as follows:

> The fossils on the whole are in very discouraging condition and in most cases it is impossible to determine them specifically.
>
> 1. Halysites catenulatus. The variety that is found, so far as known to me, only in the Silurian above the Clinton.
> 2. Heliolites cf. interstinctus.
> 3. Heliolites cf. elegans.
> 4. ? Favosites. A small ramose species.
> 5. Cyathophyllum sp. undet. A small, subcylindrical species.
> 6. Fragment of a single tube of an undetermined species of Syringopora.
>
> The above fossils are all corals of types indicating an early middle Silurian—in other words, about the age of the Louisville Niagara limestone.

No other exposures of fossiliferous rocks of this horizon are known within hundreds of miles. One of the nearest is in the Eureka region of central Nevada.

Relation to adjacent formations.—In strike and dip the limestone and the underlying quartzite are practically parallel, and their observed contacts indicate conformability. The change in the character of the sediment from siliceous sand and clay to local limestones may have been due to subsidence of the sea floor, but it did not involve deformation sufficiently great to give rise to discordance between the strata. But at about the horizon of the top of the limestone the change in sediments, which become at least locally coarse, appears to be consequent upon deformation of a more pronounced character and will be noted more fully under the Taylorsville formation.

DEVONIAN.

TAYLORSVILLE FORMATION.

Lithologic character.—The Taylorsville formation is composed for the most part of fine sediments, chiefly slates[a] and thin-bedded sandstones, among which there are numerous small layers of fine black chert or occasional less regular masses of red chert, but at the base it is locally a fine conglomerate, and near the middle there are well-defined beds of light-colored quartzite. The conglomerate at the base is greenish gray and its pebbles are indistinct. It is best exposed on the eastern face of the spur above the limestone about a mile south of Taylorsville. The pebbles are small and, in part at least, well rounded. Many of them are of igneous material more or less porphyritic. Some are rhyolitic, and in places small fragments of chert are common containing the round spots like those of the siliceous slates in the Grizzly quartzite. Thin sections of the ancient rhyolite show its groundmass very like that of some of the chert. They are easily distinguished in some cases by the presence of quartz phenocrysts on the one hand or round spots of organic origin in the other.

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[a] The Taylorsville formation was formerly called the Taylorsville slates; Bull. Geol. Soc. America, vol. 3, 1892, p. 372.

Distribution and thickness.—The Taylorsville formation is best developed a short distance south of Taylorsville, and except where cut by serpentine and pyroxenite it forms a belt southeast along the slope of Grizzly Mountains to the fortieth parallel. Like the Grizzly formation, the exposure of the Taylorsville formation ends near the fortieth parallel. Neither of them has been recognized by Turner in the Downieville quadrangle, which lies immediately south of the fortieth parallel.

Northwest of Taylorsville the outcrop of the Taylorsville formation is interrupted by alluvial deposits of Indian Valley, and it appears beyond only in isolated areas on the end of Keddie Ridge and on the Mounds, and also 2 miles north of Crescent Mills and 1½ miles west of Greenville. The last is the largest of the isolated areas and contains besides quartzite and shales some distinctly banded black cherts, in which there are no traces of organic remains. West of this area there is a small exposure in the Lassen Peak quadrangle, a few miles east of Prattville on the border of the great lava field. It is probable that some of the isolated areas mapped as Taylorsville formation north and northwest of Indian Valley contain strata which belong to the Grizzly quartzite, but in the absence of the Montgomery limestone they could not be separated.

The known extent of the Taylorsville formation is about 35 miles. For 12 miles northwest of Tower Rock on the fortieth parallel it is associated with the Grizzly formation, but beyond Taylorsville it extends alone with numerous interruptions for about 20 miles to its final cover of lava in the Lassen Peak region. The general dip of the formation throughout its extent, where not disturbed by igneous intrusions, is to the southwest.

The thickness of the Taylorsville formation in the measured section 1½ miles south of Taylorsville is about 1,800 feet. From this point it appears to thin southward. Near the fortieth parallel only 150 feet are exposed. North of Taylorsville it is so involved with igneous rocks that its thickness has not been determined, but if width of exposure may be taken as an indication the thickness increases in that direction.

Relation to adjacent formations.—The fossiliferous cherty shale pebbles in the conglomerate at the base of the Taylorsville formation appear to have been derived from the black shales of the Grizzly formation and indicate an unconformity of erosion between them, although the rocks upon both sides of the contact have essentially the same position. The lack of continuity in the Montgomery limestone suggests that the unconformity is between the limestone and the Taylorsville formation, and while this is probable it could not be fully confirmed. No pebbles of limestone were found in the conglomerate and the masses of limestone do not appear as irregular remnants left by erosion from a larger mass but are lenticular in shape, as if originally so formed.

Evidence upon this point also may be observed north and northwest of Indian Valley, where the Taylorsville formation appears to lie directly upon the quartz porphyry. The quartzite and limestone of the Grizzly formation were apparently removed by erosion from the surface of the metarhyolite before the deposition of the Taylorsville formation. The local conglomerate, associated with flinty slates and gray sandstones of the Taylorsville formation, was observed in the long, narrow strip running along the western slope of Keddie Ridge parallel to its crest. The pebbles are largely of igneous material, chiefly acid volcanics, presumably derived directly from the adjacent quartz porphyry, which the fragments closely resemble. On the whole, therefore, the evidence seems to indicate a decided unconformity of erosion between the limestone and the Taylorsville formation.

On the upper side—that is, on the southwest—the Taylorsville formation is limited by igneous rocks only. Taylor meta-andesite, a basic volcanic rock which spreads from the vicinity of Taylor Rock, overlies the Taylorsville formation on the western slope of Grizzly Mountains, but farther northwest, along Houghs Creek, granite separates it from the Arlington formation.

Age.—The only fossils found in the Taylorsville formation are sponge spicules in the cherty shales, and they are not distinctive. It is certainly younger than the Silurian, which it unconformably overlies. The abundance of the black chert layers is significant on account of the fact that the Devonian strata of the Redding quadrangle of Shasta County, about 100 miles to the northwest, are especially cherty, and in this respect contrasted with the overlying formations of Carboniferous age. In the Taylorsville region the next horizon of sediments above the Taylorsville formation is the Arlington, which is free from chert and is probably of Carboniferous age. The abundance of Devonian sediments in the Redding quadrangle leads one to expect them at this horizon in the Taylorsville region, whose general section has many features in common with that of Shasta County, and it is probable therefore that the Taylorsville formation is Devonian in age.

CARBONIFEROUS.

CALAVERAS GROUP.

The Calaveras group was named by Becker, Lindgren, and Turner in their survey of the Gold Belt to include a great body of more or less altered sandstones, shales, and limestones of Carboniferous age. It is widely distributed and occupies a greater area than any other sedimentary formation in the Sierra Nevada. Turner has mapped the Calaveras in the Downieville quadrangle, from which it extends directly across the fortieth parallel into the Taylorsville region.

In order to emphasize the essential unity of this succession of sediments in the Taylorsville region we continue to use the term Calaveras for all those sediments connecting directly with the Calaveras of the Downieville quadrangle. But to bring out the areal distribution and possibly also slight differences in age of the various parts of the Calaveras in the Taylorsville region, it is subdivided, largely as heretofore,[a] into the Arlington formation, the Shoo Fly formation, and the Peale formation, which will be considered separately before the latest Carboniferous, the Robinson formation, is taken up.

ARLINGTON FORMATION.

Lithologic character.—The Arlington formation is made up chiefly of fine, gray, thin-bedded sandstone, with some shale in part silicified and a few beds of conglomerate. It may be considered as having three members. In the lower member yellowish shales prevail, grading upward into shaly and thin-bedded greenish-gray sandstone, of which a great mass constituting the middle member is exceptionally well exposed in the bold escarpment of Arlington Heights. There is a narrow belt of yellowish-gray sandstone in the upper portion of the middle member that is somewhat coarser than the rest and is characterized by well-developed spheroidal weathering. It is composed of angular grains of fresh plagioclase, with a smaller amount of augite, green hornblende, and magnetite. Quartz, if present at all, is not common. This peculiar sandstone bears considerable resemblance to certain tuffaceous beds found in the Bragdon formation of the Redding quadrangle of California, but in the present case no definite volcanic material could be recognized either in the field or under the microscope to prove its volcanic origin.

In the upper member slaty gray shales are most abundant, with local conglomerates and highly silicified red jaspery portions near the top. The slaty shales are well exposed about Crystal Lake, where they occasionally split into thin slabs several feet in diameter. In the summit of Houghs Peak the silicification is extreme, and the mass is converted into red and gray chert veined with white quartz associated with small veins of magnetite and staining of hematite.

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[a] Geology of Taylorsville region: Bull. Geol. Soc. America, vol. 3, 1892, p. 372.

In the cliffs along the western border of Crystal Lake are beds of conglomerate interstratified with the slaty shale in which a few fossils have been found. Most of the pebbles are of gray chert, but a few are of red chert and sandstone, and locally there are a considerable number of pebbles of a holocrystalline, hypautomorphic granular igneous rock composed largely of feldspar with less chlorite and small amounts of magnetite and quartz. The chlorite probably represents original augite. The feldspar is sometimes (as in 6696) untwinned. When twinned (as in 6699) they appear to be Carlsbad showing only two bands. Rarely smaller bands appear, but evident polysynthetic twinning is certainly not present. The pebbles of igneous material are well rounded, waterworn, and very largely of the type noted above, which for the present may be called quartz-augite diorite.

The interbedded slates and conglomerates strike N. 36° W. and dip 54° SW., and the well-marked slaty cleavage is parallel to the stratification. The conglomerate is not coarse. Its largest pebbles are rarely over 4 inches through, but they have all suffered decided deformation, which reached a maximum in the plane of cleavage. The rock is cut by two systems of joints; one runs N. 40° E. and dips 69° SE., while the other strikes N. 36° W. and dips 45° NE.

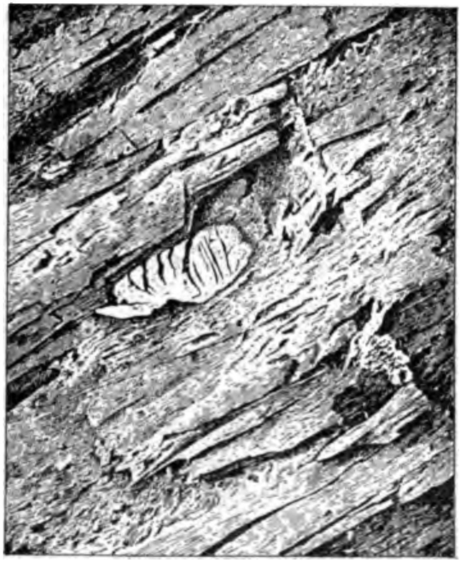

FIG. 3.—Side-fractured pebble in conglomerate of Crystal Lake.

Joints of both systems cut directly through the pebbles. On the first system the pebbles have been greatly elongated; on the second system the same pebbles are but slightly drawn out, and the greatest deformation in both cases lies in the plane of cleavage. Some pebbles are embedded in the slates and there often fractured, as shown in fig. 3 from a photograph illustrating pebbles exposed on a joint of the northeast-southwest system. The degrees of fracturing range from incipient cracks on the upper side only to complete fissuring and faulting, as illustrated in fig. 4, as if the upper part of the pebbles was in a plane of greater motion than the lower, resulting in the upper-side fracturing of many pebbles and the faulting of a few having the imbricated faulted parts inclined in the same direction as the slaty cleavage.

Distribution and thickness.—The Arlington formation has its greatest development between the summits of Houghs Peak and Houghs Creek. From this point it extends northwest into the Lassen Peak quadrangle and has been briefly described in the folio of that quadrangle. To the southeast it extends with diminishing width of outcrop to a short distance beyond the fortieth parallel into the Downieville quadrangle, where it is entirely cut off by the volcanic mass of meta-andesite ("augite porphyrite") from the vicinity of Taylor Rock. The total length of the outcrop is about 30 miles. The stratification is clearly marked with strike northwest and southeast and dip to the southwest, and with a regularity that indicates conformability throughout the entire succession of strata having a measured thickness of 5,700 feet.

Relation to adjoining formations.—The Arlington formation on the surface is completely surrounded by igneous rocks. About the southeast end and on the south and southwest the formation is limited by a great volcanic mass of meta-andesite. On the northeast it is limited by metarhyolite and serpentine in the Greenville region, but along Houghs Creek it is bounded by granodiorite. All of these bordering igneous rocks except the metarhyolite are younger than the Arlington formation and penetrate or overflow it. They separate the Arlington beds on the one hand from the Taylorsville formation and on the other from the Shoo Fly beds of the Calaveras. In general position the Arlington formation is parallel to both of these formations and lies between them.

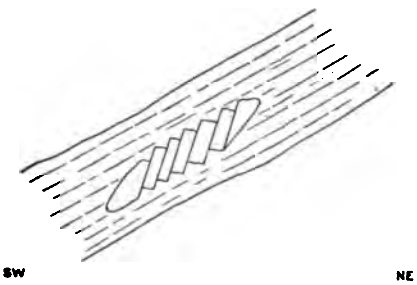

FIG. 4.—Faulted pebble in slaty conglomerate of Crystal Lake.

Fossils and age.—The only fossils found in this formation were discovered by James Storrs on the border of Crystal Lake. Girty reports from this locality "crinoid stems, coral?, *Stenopora?* sp.," and remarks that it "is probably Paleozoic, but possibly not Carboniferous." It is younger than the Taylorsville and older than the Shoo Fly portion of the Calaveras. One is probably Devonian and the other apparently Carboniferous, so that the probable age of the Arlington is either late Devonian or early Carboniferous. In the Redding region there is a great thickness of early Carboniferous sediments in the Baird and also in the Bragdon, which is poor in fossils below and in some respects, as already pointed out, like the Arlington. It is possible that the Arlington and Bragdon represent approximately the same horizon of Carboniferous below the great limestones of that system.

SHOO FLY FORMATION.

Lithologic character.—The Shoo Fly formation[a] was named from a locality on the stage road between Crescent Mills and Quincy, near the bridge crossing Indian Creek, where the beds are well exposed. They consist mainly of clay slates above and quartzite below. The clay slates are light to dark gray, generally dull, but sometimes silky and in places slightly micaceous. They contain occasional films of gray or black flinty material, as well as thin beds of sandstone and fine conglomerate of quartz pebbles, leaving no doubt as to the sedimentary origin of the formation, and yet one finds traces here and there of beds composed exclusively of volcanic fragments, some of which are clearly vesicular. Near the middle portion are lentils of limestone, some of which attain a thickness of over 50 feet and form conspicuous ledges on the spur half a mile east of Clear Creek Bridge.

The quartzites which prevail in the upper portion of the formation are thin bedded, somewhat slaty, and indistinctly schistose with micaceous partings. On a fresh fracture the quartz grains are bluish, but the rock weathers reddish. Veins of white quartz are common and locally abundant throughout the formation, and in general it may be said that the Shoo Fly beds are more affected by regional metamorphism than any other strata in the Taylorsville region.

Areal distribution and thickness.—The Shoo Fly formation occupies the southwest corner of the Taylorsville region and is well exposed on the road between Shoo Fly Bridge and Spanish Creek. This is part of the large area to the west and south around American Valley as illustrated by the areal map in the Downieville folio by Turner.

The development of cleavage in the Shoo Fly formation has obscured its stratification and rendered the determination of its thickness more difficult. A measured section makes it 6,800 feet thick, but this is probably too high.

Relation to adjacent formations.—The Shoo Fly formation is everywhere separated from the Arlington by a wide belt of meta-andesite of volcanic origin, indicating that the epochs during which the two sets of beds were deposited were separated by an interval of contemporaneous volcanic activity. The general dip of both sets of strata is to the northwest, and there can scarcely be any doubt that the Shoo Fly formation overlies the Arlington and is of later deposition.

Age.—Traces of crinoids were the only fossils found in the Shoo Fly formation of the Taylorsville region, but a few miles to the southwest, near Spanish Ranch, occur characteristic Carboniferous fossils, such as *Fusulina,* leaving no doubt as to the age of that portion of the Calaveras group.

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[a] Bull. Geol. Soc. America, vol. 3, 1892, pp. 272-275. In the Lassen Peak folio they were included in the Calaveras.

PEALE FORMATION.

Lithologic character.—In lithologic character the Peale formation is decidedly variable. Reddish to brown slaty shale, sometimes gray or greenish, passing into tuffaceous sandstone and fine conglomerate, is most common. The fine conglomerate contains much volcanic material, with occasional red lapilli and small lenses of calcareous matter. Thin beds of gray quartzite occur also, and masses of black, gray, or red chert form prominent ledges.

The tuffaceous beds are well exposed and fossiliferous on the horse trail from Wards Creek to Peale diggings, also beyond Hosselkus and to within about a mile of the Lucky S road. The chert is best exposed near the forks of the road just east of Hosselkus, where there is a prominent ledge of red banded chert full of quartz veins, but no considerable amount of hematite with it as on Houghs Peak. Red siliceous slate and chert occur near the summit along the trail from Wards Creek to Peale diggings, as well as in the divide at the head of Hinchman Ravine, but the locality for most conspicuous banding, like that of the Marquette iron-ore region of Michigan, is a mile northwest of Evans Peak and still farther in the same direction near Keddie Lake. At the last two localities, which lie beyond the limits of the Indian Valley Special sheet, the Peale beds have not been separated from the Robinson formation.

Areal distribution and thickness.—The Peale formation makes a narrow interrupted belt extending from Little Grizzly Creek north across the fortieth parallel at Peale diggings, on the divide between Wards Creek and Little Grizzly Creek, then somewhat more westerly across Genesee Valley at Hosselkus to the divide 2 miles northeast of Mount Jura, where it is covered up by the overlapping Foreman formation before reaching the Lucky S road. Small masses of these beds, chiefly red chert, adjoin the gravel of the Taylor diggings and form much of the hill at the head of Hinchman Ravine. In Keddie Ridge, northwest of Evans Peak, masses of chert occur, and they probably belong to the horizon of the Peale formation, but were not separated from the Robinson, which occurs in the same region. The thickness of the Peale formation, measured 2 miles east of the summit of Mount Jura, is about 1,400 feet.

Fossils and age.—Fossils were discovered in the Peale formation by T. W. Stanton along the trail to the Peale diggings at an elevation from 4,500 to 5,000 feet. Several collections were made by others at the same place in 1893, and all the collections were examined by Charles Schuchert, who reports the following:

Orthis michelini.
Streptorhynchus crenistria?
Ambocœlia planiconvexa.
Spirifer striatus.
Productus? sp.
Pelecypod like Yoldia or Leda.
Phillipsia sp.
Lophophyllum profundum.

In 1904 Storrs and I collected a number of fossils near the same place. They were examined by G. H. Girty, who reports (January 12, 1905) the following forms:

Fusulina sp.
Crinoid fragments.
Fistulipora sp.
Meekopora sp.
Stenopora? sp.

Girty states (May 18, 1905):

> I have also examined the collection upon which Mr. Schuchert reported. The fauna is well shown by Mr. Schuchert's list, and I regret to say seems to possess little in common with the fossils from the same area reported on January 12, 1905, which I examined, and also with those from the Robinson beds. In fact, if this fauna be brought into comparison with those of the McCloud River section, it is more nearly related to the Baird fauna than to those of the McCloud limestone or Nosoni formation. At the same time I am not prepared to definitely correlate the material examined by Mr. Schuchert with the Baird, as many of the characteristic Baird species are wanting.

There seems to be no doubt that the Peale formation is Carboniferous, and most likely older than the Robinson formation, to be noted presently. In the Downieville folio the Peale formation, which extends south of the fortieth parallel, was included by W. H. Turner in the Calaveras formation, and in the Genesee Valley region there is not sufficient reason for their separation.

The chert near Hosselkus is minutely spotted as if radiolarian. In thin section the microscope reveals the fact that the chert contains many spots with sufficient structure to enable Ulrich to determine their radiolarian origin. No trace of sponge spicules, such as are so common in the cherts of the Grizzly and Taylorsville formations, was found.

Relation to adjacent formations.—The Peale formation is almost completely surrounded by igneous rocks, meta-andesites, and is in part made up of pyroclastic material of the same sort. It is evident, therefore, that it represents approximately an epoch of volcanic activity, although the rock by which it is immediately enveloped may be in large part intrusive. This appears, at least, to be the case of the mass which splits the belt of the Peale formation into two parts southeast of Genesee.

The Peale formation dips to the southwest and overlies the meta-andesite which separates it from the Robinson formation on the northeast, but, as will be explained in considering the Robinson formation, the rocks have been overturned. Farther northwest, in the head of South Fork of Foremans Ravine, the outcrops of jaspery and associated rocks cease, and the Peale formation appears to run under the Foreman formation, by which it is unconformably overlapped. No fossils were found in that vicinity and the contact was not definitely traced.

ROBINSON FORMATION.

Lithologic character.—The Robinson formation includes a succession of variable sediments ranging from shale to conglomerate and composed chiefly of igneous material with occasional lentils of limestone. The most characteristic portion is a gray sandstone which weathers reddish brown. It contains more or less disseminated carbonates of lime forming small lentils up to 15 feet in thickness. Microscopic examination shows that the sand of which it is composed is largely of volcanic material, and includes traces of crinoids, with occasional bryozoa in many cases, even when they can not be seen with the unaided eye. Below the calcareous horizon the reddish-brown thin-bedded tuffaceous sandstone and shale extend to the bottom of the formation. Above that horizon the pyroclastic material becomes somewhat coarser and passes into a tuffaceous conglomerate containing fossiliferous limestone nodules and beds of reddish-brown sandstone, here and there with crinoid stems like that of the principal horizon below. Crystals of feldspar are common and sometimes prominent in this tuffaceous rock, giving it the general aspect of a solid lava flow, and there is good reason for surprise on finding in it distinct impressions of gasteropods, spirifers, corals, and crinoids.

Areal distribution and thickness.—The Robinson formation forms a subdivided and greatly interrupted belt, extending from 4 miles south of the fortieth parallel on Little Grizzly Creek northwest across Genesee Valley and the Lucky S mine road divide, and disappears before reaching North Arm of Indian Valley. Beyond Evans Peak it reappears, extending along the slope of Keddie Ridge, as shown in Pl. V, to its northern end, beyond Dyer Peak, where it sinks beneath the lavas of Lassen Peak. The width of the belt is from one-half to 1½ miles, and the total length is nearly 30 miles.

The belt is divided longitudinally by volcanic rocks into two subordinate belts, which cross Genesee Valley at the ranch known as Robinson's, from which the formation is named. On the north side of Genesee Valley the rocks of this formation make up the mound east of the Robinson house and the point crossed by the road west of the house. At the last locality the brown calcareous sandstones and tuffs are full of fossils. The outcrop passes between the two ledges of the Hosselkus limestone and follows the western border of that limestone northwest beyond Hosselkus Creek. It is cut off by meta-andesite along the summit of the divide, but reappears and shortly ends on the north side in a ravine leading down to Peters Creek. Several miles farther northeast on Peters Creek, running up from the trail at an altitude of about 4,500 feet, there is a small mass of characteristic reddish and gray tuffaceous sandstone enveloped by igneous rocks. The characteristic little fossils it contains leave no doubt as to its identity. Similar sandstones were found at other points along Peters Creek, but thin sections revealed no microscopic fossils. Isolated outcrops of Robinson beds occur also near the fortieth parallel among the tributaries of Wards Creek.

The thickness of the Robinson formation measured a short distance north of Genesee Valley is 1,150 feet. At that point the structure is complex and the exposure not complete, but the total thickness can not be much greater.

Fossils and age.—The first fossils collected from the Robinson formation were probably obtained by Ashburner, Brewer, and King in 1861, but sufficient characteristic fossils to determine the horizon were not obtained until 1890, when Cooper Curtice visited the region and discovered many new localities of Mesozoic and Paleozoic fossils. Since then a large number of fossils have been collected at various points from the Robinson formation, chiefly from the reddish-brown sandstone and tuff on the first spur, about half a mile northwest of the Robinson house.

December 8, 1891, C. D. Walcott reported the following fossils from the Robinson locality:

Campophyllum ? sp.
Favosites sp.
Crinoids.
Archæocidaris.
Fenestella 2 sp. undet.
Streptorhynchus crenistria.
Productus semireticulatus.
Productus punctatus ?
Spirifer lineatus?
Spirifer cameratus.
Rhynchonella sp.
Meekella like striaticostata Cox.
Aviculipecten 2 sp.
Aviculipecten interlineatus.
Myalina of subquadrata type.
Edmondia sp.
Pleurotomaria sp.

From essentially the same locality Storrs, in 1904, collected fossils numbered 6885 and 6886, among which Girty identified:

Calcareous algæ?
Fusulina elongata Shum.
Lophophyllum n. sp.
Squamularia near S. guadalupensis.
Dielasma ? sp.
Actinostroma ?? sp.
Stromatopora ?? sp.

Half a mile northwest of the Robinson locality, on the west of the ridge, at an altitude of 4,700 feet, in approximately the same beds, more fossils were collected (No. 6749), among which Girty (January 12, 1905) recognized:

Calcareous algæ?
Fusulina sp.
Rugose coral ?
Archæocidaris sp.
Rhombopora, lepidodendroides group.
Spirifer sp.
Squamularia cf. S. guadalupensis.
Spiriferina n. sp.
Aviculipecten sp.
Pseudomonotis ? sp.
Myoconcha ? sp.
Indeterminable forms.

In the collections from the conglomerate (6732–6734) between the two localities noted above Girty found:

Aulopora sp.
Striatopora n. sp.
Cystodictya sp.
Rhombopora, type of lepidodendroides.
Lophophyllum ? sp.
Streptorhynchoid brachiopod ?

Some of the fossiliferous limestone nodules in the conglomerate looked like pebbles, but their occurrence in fine beds interstratified with the conglomerate shows that the calcareous nodules are indigenous and not derived. The above lists, as far as I am aware, contain the only fossils thus far determined from the type locality of the Robinson formation on the north side of Genesee Valley.

South of Genesee Valley, near the Five Bear mine on the west side of Wards Creek, G. H. Goodhue found in the Robinson belt some imperfect fossils among which Girty recognizes the "dorsal valve of a brachiopod belonging to the genus *Meekella*, though possibly it might be a *Geyerella*." This locality is just west of the mill of the Five Bear mine, and the material looks promising for the collector.

Four miles south of the fortieth parallel, on Little Grizzly Creek, at the southern end of the Robinson belt as mapped by H. W. Turner in the Downieville folio, a number of fossils were collected at various times by Curtice and Stanton. Girty has recently examined the collections and reported the following forms:

Crinoid stems.
Archæocidaris sp.
Crania sp.
Schizophoria sp.
Orthotetes ? sp.
Meekella sp.
Chonetes n. sp.
Productus semireticulatus ?
Marginifera n. sp.
Spirifer aff. S. cameratus.
Spirifer sp.
Spiriferina aff. S. pulchra.
Squamularia lineata ?
Pugnax ? sp.
Rhynchonella sp.
Myalina sp.

Since the Robinson formation was named [a] the extensive development of the Carboniferous in the McCloud River region of California has been studied and subdivided into Nosoni, McCloud, Baird, and Bragdon. The Genesee and McCloud localities are over 100 miles apart, and from a paleontological point of view Girty has given the following statement concerning their correlations:

> The fauna of the Robinson beds is varied and interesting, although always preserved so as to make its study a difficult matter. Comparing it with the three well-characterized faunas of the McCloud River section, those of the Baird, McCloud, and Nosoni formations, one readily discovers a rather close correspondence to the Nosoni fauna, while nothing resembling the faunas of the Baird and McCloud formations has yet been found in the Robinson beds. As many species are common to the two formations, the evidence at hand certainly favors correlating the Robinson with the Nosoni.
>
> The fauna from Little Grizzly Creek, while showing certain differences from the typical Robinson, probably belongs to the same horizon. It is at least not the fauna of the Baird or McCloud.

In the foregoing lists of Girty "calcareous algæ" refers to a very minute, almost microscopic, fossil first discovered in the Carboniferous limestone of the Klamath Mountains.[b] They occur abundantly in portions of the Robinson beds and were referred to David White for examination. His report, dated December, 1905, is as follows:

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[a] Bull. Geol. Soc. America, vol. 3, 1892, p. 374.

[b] Am. Jour. Sci., vol. 20, 1905, p. 349.

> After examining excellent sections of the peculiar little fossils in the limestone from California, I am disposed to regard them as foraminiferal and having nothing whatever to do with plants. The organisms seem to be composed of successively enlarged chambers in linear arrangement, although the two or three earlier chambers occasionally show a relative position suggesting spirality. The central area of each chamber wall is somewhat irregularly perforated after the manner of various foraminiferal genera. These perforations are irregular in form and appear to have thickened margins with a greater or less amount of columnar development. The external surfaces of the chamber walls do not seem under ordinary magnification to exhibit either the perforations or the structure which are to be expected in coralline algæ.
>
> While possessing no systematic knowledge of the Foraminifera, I venture the opinion that the species is distinct from, though probably related to, *Loftusia columbiana*, though at the same time I should question its reference to the genus *Loftusia*.

The only closely related fossil reported elsewhere in the Carboniferous of the Sierra Nevada is noted by Turner in the Bidwell Bar folio, page 3, from Edmanton, about 10 miles southwest of Quincy. The original specimens on which Schuchert's determination was based are not available for comparison, but it is not improbable that they are identical with those of Genesee Valley and Klamath Mountains and that the Robinson formation occurs at Edmanton.

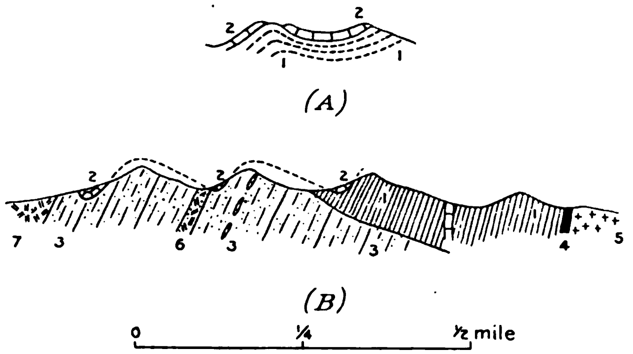

FIG. 5.—Sections of spurs north of Genesee Valley near Robinson's. 1, Swearinger slate; 2, Hosselkus limestone; 3, Robinson formation; 4, contact zone (hornfels); 5, granodiorite; 6, Reeve meta-andesite and tuff; 7, Taylor meta-andesite.

Relation to adjacent formations.—The older rocks to which the Robinson formation is related are the Taylor meta-andesite and the Peale formation upon the southwest, while the newer beds, the Hosselkus limestone, Swearinger slate, and Trail formation, lie upon the northeast. First as to the older formations. As stated in connection with the Peale formation, they are separated from the Robinson formation by a belt of Taylor meta-andesite. It is a volcanic rock with pronounced porphyritic structure. In some places the most prominent phenocrysts are plagioclase; at others they are augite. The tuffaceous conglomerate and sandstone of the

Robinson formation are composed almost wholly of volcanic material erupted in connection with the effusion of the mass of meta-andesite. They dip to the southwest beneath the sheet of volcanics which was the source of their material. That they have been overturned is demonstrated not only by this inverted succession but also by the fact that both the meta-andesite and the Robinson formation dip southwest beneath the Peale beds, which, as the fossils show, are of still greater age.

The relation of the Robinson formation to the newer strata, the Hosselkus limestone and Swearinger slate, which lie mainly upon the northeastern border, is shown in fig. 5, *A* and *B*, which illustrates a section running across the points of limestone a mile and a half northeast of Genesee. In that locality the Robinson beds evidently lie unconformably beneath all the later formations with which they come into contact.

TRIASSIC.

HOSSELKUS LIMESTONE.

Lithologic character.—The Hosselkus limestone is dark blue on fresh fracture, but weathers light gray, and contains a few veins of white calcite. It is thin bedded and in some places decidedly slaty, forming prominent ledges on the divide between Genesee Valley and Hosselkus Creek, a mile northeast of the Hosselkus ranch, from which the limestone was named. It is well characterized by small ammonites. Although they are not only uncommon but indistinct, yet they readily serve as a means of distinguishing this limestone from any other. In the Redding region, where this limestone is particularly well developed, the upper part is lighter colored and more massive, with a spirifer-like shell, and the lower part thinner bedded and darker, with small coiled forms, but in the Taylorsville region no such differences are apparent.

Distribution and thickness.—The most important outcrops of this limestone are on the divide already indicated north of the Robinson place. It forms two hills on the crest, running nearly northeast for half a mile, then turns northwest and crosses the valley of Hosselkus Creek, but soon disappears. This continuous exposure is only about 2 miles in length, but an isolated outcrop occurs at each end along the strike, one at the head of a ravine tributary to Peters Creek and the other near the road a mile east of Hosselkus, increasing the total length of exposure to about 6 miles but not extending it beyond North Arm to the northwest or Genesee Valley to the southeast.

Several isolated outcrops of the Hosselkus limestone occur on the lower slope of Grizzly Mountains, a mile southwest of the mouth of Little Grizzly Creek. They contain irregular patches of cherty matter and traces of crinoid stems, both round and pentagonal. These outcrops are approximately in line and make an exposure nearly a mile in length. The general strike is N. 5° E., and the dip 70° NW. into Grizzly Mountains. Over 50 feet of limestone are exposed. Traces of red beds occur at its base, though it is for the most part directly in contact with the meta-andesite. Just above the limestone black flinty material occurs which suggests some of the Swearinger slate, and judging from the size and character of the limestone, as well as its fossils and association, there appears to be little doubt that this mass really belongs to the Hosselkus limestone.

Notwithstanding its restricted occurrence in the Taylorsville region, it is more widely distributed to the northwest in the Lassen Peak quadrangle, where it is included with other sediments in the Cedar formation. In the Redding quadrangle, where it has its greatest development, it is rich in fossils and remarkable for its lenticular character. The greatest thickness of the Hosselkus limestone in the Taylorsville region is about 140 feet.

Fossils and age.—The fossils collected from this limestone by Professor Hyatt and others in the Taylorsville region have not yet been fully worked up. A partial list is given by Hyatt:[a]

> 1. *Arcestes*—phylum of *A. tornati.*
>   *Arcestes*—phylum of *A. galeati.*
>   *Arcestes*—phylum of *A. bicarinati.*
>   *Arcestes*—phylum of *A. sublabiati.*
>
> *Badiolites*, allied to *B. eryx* Mojsis.
> *Juvavites*, allied to *J. erlichi* Mojsis.
> *Tropites*, may be young of species occurring in *Halobia* slates.
> *Atractites.*
>
> *Arcestes* (I) is very abundant, but whether the other forms are abundant or not it is difficult to say at present. The materials gathered show that the rock is full of fossils, but these can not be obtained in any reasonable time by means of surface work. Besides the species mentioned, there is a form of *Acrochordiceras*, with finer costæ than those occurring in the Muschelkalk, a possible *Balatonites*, like *B. waageni* of the Noric, and some other fragments of ceratitinæ, all indicating a fauna rich in ammonoids, which will some day yield a good harvest to patient work.

Professor Hyatt concludes that the age of the Hosselkus limestone as indicated by the fossils is upper Triassic. To this list *Spiriferina* and fish vertebra, as determined by Stanton, were added last summer. This limestone has not yet been thoroughly examined for reptilian remains, such as J. C. Merriam has found in the Redding quadrangle, but as the limestone of the Taylorsville region is more altered and much less fossiliferous, reptilian remains are less likely to occur. In the Redding region the more massive upper portion of the Hosselkus limestone is characterized by the presence of *Spiriferina*, while the lower, darker, thin-bedded portion often abounds in small ammonites. In the Taylorsville region an attempt was made to determine the upper and lower sides of the limestone by its fossils

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[a] Bull. Geol. Soc. America, vol. 3, 1892, pp. 399-400.

Spiriferina was found at only one point on the side adjoining th Swearinger slate. In this respect it agrees with the Redding region and tends, as we shall show later, to confirm the view that th Hosselkus limestone on the crest of the divide north of Genesee Valley is overturned. It should be noted, however, that the small coile forms of *Arcestes* are most abundant on the same side, which does no strengthen the view concerning the *Spiriferina.*

Relation to the Robinson formation.—The reference of the Hosselku limestone to the upper Triassic and the Robinson formation to th upper Carboniferous indicates a decided gap between them, a ga which is at least partially filled in the more complete section of th Redding region, where a great thickness (over 1,000 feet) of andesiti and rhyolitic lavas, with 1,500 feet of overlying shales, sandstones and tuffs of Triassic age, comes between the horizon of the Robinso formation and that of the Hosselkus limestone. It is evident, therefore, that in the Taylorsville region there is a decided interruptio between the Hosselkus limestone and the Robinson formation. It i possible, however, that their contact in the Taylorsville region is plane of displacement, and that the formations of the Redding regio missing in the Taylorsville region may, in part at least, be thu accounted for. This matter will be considered more in detail in th discussion of the relation of the Swearinger slate to adjacent formations. (See fig. 5.)

SWEARINGER SLATE.

Lithologic character.—The Swearinger formation is composed chiefl of dark slaty shale, sometimes becoming more or less calcareous an at others decidedly siliceous, but the thin beds of limestone or cher form only a small proportion of the whole mass. In the side of th Swearinger slate adjoining the Hosselkus limestone thin lenticula beds of limestone become more abundant. They are generally dark with irregular cherty or sandy layers, and fossiliferous.

Distribution.—The Swearinger slate has a very limited distributio in the Taylorsville region. Its best exposure is on the spur which w called "Triassic spur," running up from Swearinger's house and sprin to the point of Hosselkus limestone near the crest where the are divides. A small part keeps southwest of the limestone and crosse over to the spur, which is chiefly of Robinson beds. On this spu which has been called the "Carboniferous spur," near the limeston is the locality of Hyatt's "*Halobia* bed," while the *Monotis* be *Daonella* bed, and *Rhabdoceras* bed of Hyatt are on the "Triassi spur."

The main body of the Swearinger slate extends north along th eastern or northeastern side of the Hosselkus limestone for about 2 miles from Genesee Valley, gradually narrowing to the northwest an finally disappearing. It could not be found along Hosselkus Creek where the Trail formation comes into contact with the Hosselkus limestone, nor south of Genesee Valley, where the Trail formation comes in contact with the Robinson. The outcrop of the Swearinger slate in the Taylorsville region is limited along the strike to a distance of less than 3 miles and a width where greatest of about a third of a mile. Along the eastern border it is much altered in contact with the granodiorite of the region.

Thickness.—The greatest thickness of the Swearinger slate exposed along Genesee Valley, where measured, is about 200 feet, but the amount cut off by the granodiorite or covered by the overlapping Trail formation we have no means of estimating except by comparison with formations of the same horizon in other regions; such comparison indicates that the thickness is probably not over 400 feet.

Fossils and age.—The fossils of the Swearinger slate were discovered and described by the Geological Survey of California under Prof. J. D. Whitney. Our knowledge of the fauna was greatly extended by Prof. Alpheus Hyatt, who has published[a] lists of the forms found in the subordinate paleontological horizons within the formation. They need not be repeated here except to note that the form from these beds once regarded as *Monotis subcircularis* is now considered by J. P. Smith and others to be *Pseudomonotis*. Professor Hyatt regarded the Swearinger slate as belonging to the upper Triassic, equivalent to the upper Noric of the Alpine Triassic, and as far as I am aware this reference has not been changed essentially by the somewhat later researches of Professor Smith.

Relation to adjacent formations.—The general dip of the Swearinger slate is to the southwest beneath the Hosselkus limestone, and on this account it was at first supposed[b] to be older than the Hosselkus limestone. In the Redding quadrangle of Shasta County, where these Triassic rocks are extensively exposed and much less disturbed, Prof. J. P. Smith discovered that the *Pseudomonotis* horizon, corresponding to at least part of the Swearinger slate, is above instead of below the Hosselkus limestone.[c] A study of the same region as set forth in the Redding folio confirms us in the same opinion, and shows that in the Taylorsville region the Triassic has been overturned, reversing the natural order of superposition. Everywhere the Swearinger slate and the Hosselkus limestone are essentially conformable. In the Taylorsville region they do not appear coextensive, but this lack may be due to displacement.

The only other sedimentary formation with which the Swearinger slate comes in contact is the Robinson, and judging from their faunal relations, belonging, respectively, the one to the top of the Triassic and the other near the top of the Carboniferous, they must be in unconformable contact, and the discordance must represent a time interval of long duration, an interval which is represented in the Redding region, as already explained, by a great thickness of lavas overlain by 1,500 feet, chiefly of shales—the Pit formation, belonging to the middle Triassic. The conformity of the Swearinger slate and the Hosselkus limestone and the unconformity of both on the Robinson formation is shown in fig. 5, *A* and *B*, which illustrates a section near Robinson's place.

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[a] Bull Geol. Soc. America, vol. 3, 1892, pp. 397-400.

[b] Idem, pp. 272 and 395.

[c] Jour. Geology, vol. 6, 1898, p. 778.

Beginning with the limestone on the left-hand spur, where it has been burned for lime, we find it contains fossils that identify it with the Hosselkus limestone of the next two spurs to the east. This spur is made up chiefly of slates in which no fossils have been found. The first ravine toward the right is cut in meta-andesite, the eastern side of which is tuffaceous and belongs to the Robinson formation. The tuff and calcareous sandstone both contain an abundance of Carboniferous fossils, and in connection with the tuffaceous conglomerate which underlies the sandstone they form the second spur of the section, fig. 5, *A*, up to an elevation of 4,500 feet. Above that point, as shown in fig. 5, *B*, the spur is composed of *Halobia* beds of the Swearinger slate overlain by the Hosselkus limestone, and both are fossiliferous. They form an arch over the spur to both ravines, down which they extend far enough to appear in fig. 5, *A*. The strike of the Robinson formation on the lower part of the spur carries them unconformably beneath the Triassic arch, and it is evident that the line of contact between Paleozoic and Mesozoic is one of displacement, along which the overturned Triassic was shoved eastward across the truncated edges of the Robinson formation. The local disappearance of the Swearinger slate between the Hosselkus limestone and the Robinson formation is most likely due to displacement.

JURASSIC.

GENERAL ACCOUNT.

There are seven Jurassic formations of the Taylorsville region. The Trail formation is the oldest; then follow the Hardgrave sandstone, Thompson limestone, Mormon sandstone, Bicknell sandstone, Hinchman tuff, and Foreman formation in regular succession. With the exception of the last their surface distribution is limited to a comparatively small area about Mount Jura, and to facilitate matters it may be stated here that the whole set of beds have been overturned and that the Hardgrave sandstone apparently lies on top. In their attitude they are like the Triassic and Carboniferous, already described. The strike is northwest and the dip southwest.

TRAIL FORMATION.

Lithologic character.—The Trail formation includes a mass of strata composed largely of slaty shales with some interbedded sandstones and conglomerates. It is well exposed along Hosselkus Creek on the trail, hence the name. The shales are often purplish or red, but perhaps more frequently gray, with pencil structure locally developed, and contain in places numerous cherty nodules of carbonate of lime. Well-marked slaty structure is not uncommon. The sandstones are generally fine, often somewhat slaty, are thin bedded, and vary from gray to almost black. The conglomerates of slate and sandstone pebbles, sometimes 3 inches in diameter, generally contain much volcanic material. Approaching the contact with the granodiorite in many places the fine sediments become darker and more compact, with conchoidal fracture, and pass into regular hornfels, a specimen of which from Hornfels Point is No. 134 in the Educational Series of Rocks.[a] Some of the beds of tuff are well defined, ranging from 10 to 50 feet or more in thickness, and occasionally coarse. Tuffaceous conglomerates are most abundant on the side toward the Swearinger slate, but extend throughout the formation, and a strip of 50 feet of slaty conglomerate occurs in the volcanics which bound the sediments on the northeast.

Distribution.—There are two principal areas of the Trail formation, one north of Genesee Valley and the other south. That north of Genesee Valley is blunt wedge-shaped, with its base 2 miles in width along Hornfels Point, where the sediments have been greatly altered by the underlying granodiorite. This area borders the Swearinger slate and Hosselkus limestone, crosses Hosselkus Creek, but is cut off by the volcanics before reaching the Lucky S road. From near its southeast corner it sends off two irregular projections. The long, narrow strip running northwest across Hornfels Point to Hosselkus Creek is chiefly slaty, sometimes pebbly shale. The bedding dips 83° SW. and strikes N. 50° W., parallel to the course of the belt, which is in places only 60 feet in width, and is bounded on both sides by volcanic rocks related to metaaugite andesite. The projection running east lies between the granodiorite and the volcanics. Much of it is greatly altered by the underlying granodiorite, and, consisting largely of volcanic material, may perhaps belong with the volcanics on the north rather than to the Trail formation.

From Genesee Valley the Trail formation extends southeast to the basalt flows of Ingalls Peak. It lies between the granodiorite on the one hand and andesite porphyry on the other, except for a short distance northeast of Genesee mine, where it comes in contact with the slates of the Robinson formation. The total length of the exposure of the Trail formation along the strike is about 7 miles and is limited in both directions by volcanics.

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[a] Bull. U. S. Geol. Survey No. 150, 1898, p. 337.

Thickness.—The thickness of the Trail formation was measured on the prominent spur next north of Hornfels Point descending into the sharp bend of Hosselkus Creek and found to be about 2,900 feet.

Fossils.—Fossils have been carefully sought for in the Trail formation, but with little success. However, traces of plants and animals have been found together at an elevation of 5,600 feet on the next spur north of Hornfels Point, and also a half mile northeast of the Gruss mine at an elevation of 4,700 feet south of Genesee Valley. Nothing whatever could be made of the plants, but of the other fossils Stanton reports "undetermined small bivalves, possibly *Estheria*, a crustacean. It is a nonmarine genus occurring in fresh or brackish water and is a common form in the Trail beds. Similar fossils occur in the Carboniferous as well as in Triassic and later formations." It is evident therefore that the fossils furnish little aid in determining the taxonomic position of the Trail formation. For this we must depend chiefly upon its apparent relation to the Swearinger formation.

Relation to Swearinger formation.—The general dip of the Trail formation on the measured section is southwest at an angle ranging from 35° to 80°, and it passes directly beneath the Swearinger slate and Hosselkus limestone. Attention has already been called to the fact, well illustrated in the Redding region, that the Swearinger slate is younger than the Hosselkus limestone and that in the Taylorsville region it has been overturned. This overturning includes also the Trail formation, and indicates that the Trail formation is the one next newer than the Swearinger. It seems evident also, from the way in which the Trail formation overlaps first the Swearinger slate and then the Hosselkus limestone to the Robinson formation, that the Trail formation is unconformable on all of them. The only other rocks, besides those just mentioned, that come in contact with the Trail formation are granodiorite and the various volcanics by which the Trail formation has been covered and its exposures limited.

Correlation.—The horizon of the Trail formation, as far as it can be made out in the Taylorsville region, appears to be unconformably over the Swearinger slate, in essentially the same relative position as the Modin formation of the Redding quadrangle at the base of the Jurassic sediments. Lithologically the two formations are similar and may be regarded as approximately equivalent, but this correlation secures no direct support from the paleontologic evidence. The Modin formation is locally rich in fossils and they occur in many places, although there are many other places where none could be found. Stanton compared the two faunas and reports that "*Estheria* has not been found in the Modin formation, but its absence from that formation is to be expected because all the fossils known from it are marine. The fossils present no serious objections to regarding the Modin and Trail beds as time equivalents."

The relation of the Trail formation to the Hardgrave sandstone, which in the Taylorsville region is its successor, will be considered with the later formation.

HARDGRAVE SANDSTONE.

Lithologic character.—The Hardgrave sandstone is red or gray in color. It varies from fine shaly sandstone to conglomerate and is almost wholly of a tuffaceous character. The most common color is red, ranging from brick red to dull brown, but much of it is gray, and the two colors are intermingled irregularly in the same bed. The bedding is generally well marked, but in a few localities the massive outcrops show little trace of stratification. Where the sediments are fine the sandstone passes into shale, which occasionally shows a decided slaty cleavage and breaks up into long, slender, pencil-shaped fragments. Generally the sandstone is so fine as not to appear granular and breaks with a splintery fracture. The rock is firmly lithified and yet is comparatively soft, owing to the weakness of the calcareous cement. When the coarser forms of Hardgrave sandstone are broken the fracture generally passes around the grains instead of through them, allowing them to stand in relief upon the fracture surface and make it rough. Rarely it is hard and flinty, much fractured, and veined. In acid both the red and gray varieties effervesce freely, and locally they contain small limy patches. Carbonate of lime is the principal cement, but in the red and weathered forms oxide of iron plays an important part. Near its contact with igneous rocks it is colored yellowish green by epidote. Coarse gray sandstone and fine conglomerate are much less abundant than the finer forms. They afford a much better opportunity to see the volcanic character of the material. It is mainly volcanic sand, made up of crystal fragments of plagioclase feldspar with many lapilli, usually more or less vesicular, and often filled with minute lath-shaped crystals of feldspar, which are for the most part so altered that their polysynthetic twinning, if present, can not be seen. Many of the feldspar fragments are plagioclase, but a somewhat smaller number appear to be orthoclase and possibly some quartz. One of the striking features of this sandstone, apparent only on microscopic examination, is the paucity of quartz.

Distribution.—The Hardgrave sandstone is limited in its distribution within the Taylorsville region almost exclusively to the slope of Mount Jura, and occurs in two belts. One, the main belt, lies along the western base of Mount Jura, and the other, the crest belt, lies near the crest of the prominent spur running south from the summit of Mount Jura.

The main belt, wavy in its course, runs southeast almost continuously along the western base of Mount Jura from North Arm, near

Dead Fall Lane, to Huntington's, and beyond to the lower slope of Grizzly Mountains, where two small areas mark its termination against a great mass of ancient quartz porphyry. The total length of this belt is a little over 4 miles, with a width ranging from a few feet to a third of a mile. This belt is the most accessible, and, lying on steeper slopes, contains better exposures than most of the other areas. Coarse gray calcareous sandstone, weathering very rough, crops out at a number of points along the western border, and east of it the finer red and gray beds occur. They are well exposed by the road a short distance northeast of Taylorsville, opposite the steel bridge, and about a mile farther southeast, near Donnerwirth's, but outcrops occur throughout the greater portion of the belt, though somewhat less abundant and conspicuous than those of the meta-andesite next eastward. The strike of the beds everywhere is approximately parallel to the course of the outcrops, and the dip is westerly. The interruptions in this belt east of Taylorsville, opposite the mouth of Montgomery Creek and on the lower slope of Grizzly Mountains, are due chiefly to the eruption of the meta-andesite.

The next most important area is the one which parallels the first in the crest belt. It is a narrow belt extending a little east of south from the summit of Mount Jura along the crest overlooking Hinchman Ravine. In lithology and fossils it is in the main identical with the belt just noted, but near the summit is somewhat more crushed and veined.

Between these two belts on the western slope of Mount Jura there are five smaller masses, three of which lie directly southwest of the Jura summit, one farther south, and another, the largest of the separated masses, lies a little farther north. A more isolated small area lies at an elevation of 4,500 feet on the northern end of Mount Jura, near the old lime road.

There is only one other area to mention, and that is one of the smallest and most isolated. It is about three-fourths of a mile northeast of the stage road at the crossing of Hinchman Ravine, and was discovered by the indefatigable Curtice. Lying outside of the area marked out by the two belts on Mount Jura, its degree of isolation is very much greater than that of any of the other areas in the region. The identification of all these isolated masses rests on paleontologic as well as lithologic evidence, and the attitude of the strata with westerly dip is essentially the same in all the areas.

The extremely limited and patchy distribution of the Hardgrave sandstone within a few square miles about Mount Jura is a striking feature. It does not occur anywhere else in the Sierra Nevada, but 80 miles to the northwest it has an extensive development along the border of the Klamath Mountains in connection with the Potem formation. The interval is now covered largely by the lavas of Lassen

Peak, but during the Jurassic the two areas must have been directly connected.

Thickness.—The maximum thickness of Hardgrave sandstone as measured half a mile north of Donnerwirth's may be 850 feet, but is possibly much less, for the measurement involves a large talus-covered slope in which the limit of the sandstone could not be definitely determined. At a number of points in the same belt 250 feet of red and gray beds are well exposed. In the crest belt running south from the summit of Mount Jura two measurements were made. One-third of a mile from the summit the Hardgrave sandstone is 112 feet in thickness, and three-fourths of a mile from the summit, near the crest at the head of a prominent spur descending southeast to the mouth of Hinchman Ravine, it is 124 feet in thickness; the upper 54 feet are gray sandstone partly coarse, while the lower 70 feet are red. It is evident that in the main belt the sandstone is much thicker than in the crest belt. It decreases in thickness and runs out against older formations to the south, but northward it may continue its thickness beneath newer formations.

Age.—The paleontologic investigations of the Hardgrave sandstone were made by the late Prof. Alpheus Hyatt, whose preliminary report is as follows:[a]

> The Hardgrave sandstone contains the remains of a very abundant fauna and the fossils are sufficiently well preserved.
>
> The most abundant species are the following: *Pecten acutiplicatus*, Meek, is to be expected wherever this sandstone occurs, and can be called its characteristic fossil in this region; *Entolium meeki* is perhaps the next in abundance and is almost as widespread in distribution; *Pinna expansa* is not found everywhere, but it forms banks like *Ostræa* or *Unio* in some places and is often found associated with the two above named.
>
> The age of the Hardgrave has been determined by cumulative evidence. That it was probably a member of the Lias, as previously stated by Prof. Jules Marcou, became evident after a preliminary examination of the fossils, but the facts leading to the conclusion that it is more likely a member of the upper Lias than of the lowest Lias were more difficult of acquisition. It contains many fossils having affinities with those of the lowest or infra Lias, and the *Modiola* and *Mytilus* might even have occurred in the uppermost Trias or Rhætic. On the other hand, some forms have very close relations to the same genera as they appear in the Mormon sandstone, or Oolite, of the same locality. *Pinna*, *Gervillia*, *Ctenostreon*, *Entolium*, *Trigonia*, and *Cidaris* show an assemblage of upper Lias types. The species of *Entolium* and *Ctenostreon* are closely related to those of the Oolite above, and one species of *Trigonia* resembles the young of a species from the Oolite of western Europe. The most conclusive evidence, however, is furnished by the single well-preserved specimen of *Glyphea*, which I was so fortunate as to find in the typical locality close to the village of Taylorsville, and the *Goniomya*, allied to *G. v-scripta*, Agassiz.
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> The 42 species exhibited, which were selected from the collections of the Geological Survey, do not represent the entire fauna. I have still further restricted the list given below to those species which are either characteristic or have been described and figured or can be closely compared with representative European species.

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[a] Bull. Geol. Soc. America, vol. 3, 1892, p. 401.

Taylorsville, Cal.	Europe.
Montlivaultia, n. sp. (?)	*M. haimei*, Chap. et Dewal.; lower Lias.
Ostræa, sp	*Ostræa irregularis*, Chap. et Dewal.; inf rior Lias to middle Lias.
Ostræa, n. sp	*Ostræa arietis*, Quenst.; lower Lias.
Anomia, n. sp	*Anomia striatula*, Terq. et Piette; low Lias.
Modiola, n. sp	*Modiola psilonoti*, Quenst.; lower Lias.
Mytilus, n. sp	*Mytilus psilonoti*, Quenst.; lower Lias.
Mytilus, n. sp	*Mytilus terquemianus*, Chap. et Dewal lower Lias.
Pinna expansa, n. sp	*Pinna hartmanni*, Auct.; lower Lias.
Gervillia linearis, n. sp	*Gervillia lanceolata*, Quenst.; upper Lias
Gervillia gigantea, n. sp	*Gervillia aviculoides*, Quenst.; Oolite.
Gervillia gigantea, n. sp	*Gervillia betacalcis*, Quenst.; middle Lias.
Lima, n. sp	*Lima nodulosa*, Terq. et Piette; lower Lia
Lima, n. sp	*Lima charta*, Dum.; lower Lias.
Lima, n. sp	*Lima galathea*, Dum.; upper Lias.
Ctenostreon, n. sp	*Lima tuberculata*, Dum.; lower Lias.
Pecten acutiplicatus, Meek	*Lima acuticostata*, Schübl.; inferior Oolit
Lima sinuata, Meek	
Lima recticostata, Meek	
Pecten, n. sp	*Pecten textorius*, Goldf.; Lias and Oolite.
Pecten, n. sp	*Pecten dextilis*, Münst.; Lias and Oolite.
Entolium meeki, n. sp	*Pecten demissus*, Goldf.; Lias and Oolite.
Goniomya, n. sp	*Goniomya v-scripta*, Ag.; upper Lias.
Pholadomya, n. sp	*Pholadomya ambigua*, Sow.; upper Lias.
Pleuromya, n. sp	*Pleuromya striatula*, Dum.; upper Lias.
Trigonia, n. sp	*Trigonia costata*, Sow.; middle Lias.
Trigonia, n. sp	*Trigonia costatula*, Lycett; inferior Oolit
Cidaris, n. sp	*Cidaris*, Quenst.; upper Lias.
Glyphæa punctata, n. sp	*Glyphæa solitaria*, Opp.; inferior Oolite.

I showed the unique fossil *Glyphæa punctata*, of which the carapace (with the exce tion of the tip of the rostrum) is well preserved, to Prof. Walter Faxon, of the Museu of Comparative Zoology, well known as an expert carcinologist, and he at once plac it in the Jura under the name *Glyphæa*. *G. solitaria*, Opp., of the lowest Oolite, zo of *Trigonia navis*, is not only very close to our American form in the characteristi of the sutures of the carapace, but the surface has the rare sculpturing of punct tion in place of the usual tuberculation found in most species of this genus, a peculia ity also characteristic of *G. punctata*. Such forms as these and the evidently clo alliance and probable continuity of the fauna through migration with that of tl Mormon sandstone suggest that the Hardgrave sandstone should be classed as upp Lias in spite of the large number of forms which are represented by species occurri also in the lower and middle Lias in Europe.

The homogeneous character of the rock and the association of fossils found in tl larger masses of it led also to the conclusion that it represented only one bed in tl upper Lias, but such minute researches as would have established this beyond que tion were not practicable.

Relation to adjacent formations.—The next sedimentary formatic older than the Hardgrave sandstone is the Trail formation. The are not known to occur in contact or even near each other in tl Taylorsville region, but from the fact that the Trail beds are fresl water deposits and the Hardgrave sandstone marine, they may be assumed to be unconformable.

The sedimentary formation next newer than the Hardgrave sandstone is the Thompson limestone. They have not been found in actual contact, but sometimes near together, separated only by a sheet of meta-andesite. Their essentially parallel position when near together indicates conformability. The Hardgrave sandstone at several points is in contact with the Mormon sandstone, but, as we shall see later, it is the result of faulting.

The Hardgrave sandstone is almost everywhere in contact on the one hand with an ancient rhyolite and on the other with meta-andesite. The metarhyolite is on the western side of the Hardgrave sandstone and lies upon it. The sandstone throughout its course in both belts dips westward beneath the ancient rhyolite and is composed, as already pointed out, of lapilli and débris derived from the rhyolite. It is therefore younger than the rhyolite, and their position has been reversed by overturning.

The contact of the Hardgrave sandstone with the meta-andesite along its eastern border is less regular than that of the metarhyolite on its western. The dip of the sandstone is west, and in many places it appears to rest directly on the meta-andesite, which passes beneath it with the same inclination. In other places—and these are important—the igneous rock breaks through the bedding and incloses many fragments of the sandstone, showing clearly that its eruption took place after the sandstone was deposited. The included sandstone fragments may be distinctly seen at an elevation of 4,100 feet in the ravine about a mile north of Donnerwirth's, as well as at other points near the contact within the area of the meta-andesite. The fragments are generally small and red, with the lithologic character of the Hardgrave sandstone, but no fossils were found in them. Though the sandstone along the contact is not clearly altered, the igneous rock is often perceptibly finer grained near the border, owing to the cooling influence of the sandstone. There seems to be scarcely room for doubt that the meta-andesite is younger than the Hardgrave sandstone.

THOMPSON LIMESTONE.

Lithologic character.—The Thompson limestone is gray and somewhat shaly, and on its weathered surface in places are round, oblong, or irregular patches of darker more or less granular calcite, which at once suggests fossils, though their specific determination is a matter of difficulty. Where shaly it is generally red, highly argillaceous, and locally full of long, slender gasteropods, which weather out and leave the porous argillaceous skeleton of the limestone full of "screw holes."

Areal distribution and thickness.—The Thompson limestone, like the Hardgrave sandstone, outcrops in two belts. The main belt crosses the west slope of Mount Jura, and the crest belt lies along the crest running south from the summit of Mount Jura.

The main belt is irregular and interrupted, extending south across the west slope of Mount Jura from Mr. Thompson's on North Arm to the lower slope of Grizzly Mountains, a mile southeast of Huntington's, and the most prominent and accessible exposures are near the north end, where it has been burned for lime. At Thompson's it forms a bluff, strikes N. 70° W., dips 40° SW., and has a thickness of 30 feet.

A mile to the southeast the limestone is interrupted and offset nearly half a mile to the east. At an elevation of 4,100 feet outcrops begin again and have furnished material for lime. The mass at this point has a thickness of 40 feet and curves in position from N. 53° W. to N. 28° W., with a dip of about 40° to the southwest. It contains a number of irregular forms supposed to be sponges. The bottom layer of limestone is massive, 6 feet in thickness, and has a rough weathered surface. Below the limestone reddish and gray beds are exposed interstratified with limy layers. Above the limestone are 10 feet of red shaly limestone or calcareous shales locally full of *Nerinea*, the screw-shaped gasteropod to which allusion has already been made. At this locality the limestone changes its course from southeast to southwest and follows a prominent spur toward Taylorsville. The red shaly limestone and calcareous shale is more abundant and continuous than the lentils of gray limestone, and the whole mass is folded and displaced in a complicated fashion along lines running southeast, producing a local extension in that direction before the general course is resumed a mile farther southwest. On the prominent spur running a little south of west from the summit of Mount Jura is a small isolated patch of red beds belonging to the Thompson limestone horizon. Their strike is N. 15° E. They are highly calcareous, fragmental in appearance upon a weathered surface, and contain small nodules and lenses of gray limestone as large as 18 inches in diameter. Traces of fossils appear in the gray limestone and also in the red beds, but none are well enough preserved for specific determination. On the next spur, half a mile farther south, is a small mass of gray limestone 10 feet in thickness with irregular cherty portions. It is directly in the course and horizon of the Thompson limestone, but no fossils were found in place at this point, though they occur near by in the talus and in place a mile farther southeast beyond the interruption. On the spur running up from the Narrows the calcareous red beds with the characteristic fossils of the Thompson limestone reappear and continue to the road above Huntington's. On the lower slope of Grizzly Mountains, in the southwest quarter sec. 7, T. 25 N.,

R. 11 E., the terminal outcrops of this belt of Thompson limestone appear in three isolated ledges lying along a line extending nearly east and west. Some of the limestone outcrops strike N. 36° W. and dip 45° SW., a position which connects it directly with the Thompson limestone of Mount Jura, while other portions strike N. 70° E. and dip 50° SE., probably as the result of a fault. The limestone exposed at this point ranges from 4 to 25 feet in thickness. It looks like the Thompson limestone but contains only traces of indefinite fossils. However, its general relations to other formations leave no doubt as to its horizon.

The only outcrop of Thompson limestone lying outside of the main belt just described is in the crest belt of exposures extending south from the summit of Mount Jura. It occurs near the top of the spur rising northwest from the mouth of Hinchman Ravine, at an elevation of about 5,100 feet, and contains the curious spongelike forms, while the associated red beds have definite characteristic fossils. The total thickness of the formation at this point is probably less than 20 feet and its outcrop is scarcely half a mile in length.

The Thompson limestone has not been identified anywhere beyond the immediate vicinity of Mount Jura. Considering its size and variability, this is not a matter of surprise.

Relation to adjacent formations.—The relation of the Thompson limestone to the meta-andesite that bounds it upon the west may be clearly seen on the northern slope of Mount Jura, near the end of the lime road, where the red calcareous beds, full of slender gasteropods, come into direct contact with the altered andesite. The fossils lie parallel to the surface of the volcanic rock, practically against it, without showing any alteration due to the presence of the igneous rock. This relation evidently indicates that the limestone was deposited upon the meta-andesite and is of later age. It has already been shown that the same meta-andesite is younger than the Hardgrave sandstone. The general dip of the Thompson limestone is to the southwest beneath the meta-andesite by which it is bounded in that direction, and both pass beneath the Hardgrave sandstone. All have been overturned together.

On the eastern side the Thompson limestone appears to conformably overlie the Mormon sandstone, though their actual contact is rarely exposed. A small mass of rhyolite separates them on the steep slope overlooking North Arm, but a short distance farther south they outcrop near together in parallel positions.

In SW. ¼ sec. 25, T. 26 N., R. 10 E., where the limestone turns abruptly and extends east for nearly half a mile, it appears to be held directly in a downward fold of the Mormon sandstone. The two isolated outcrops west and southwest of the summit of Mount Jura, as well as the one in the crest belt south of the summit, clearly show, as illustrated in fig. 11, that the Thompson limestone rests upon the Mormon sandstone, and that its taxonomic position is between the Hardgrave and Mormon sandstones. It must be remembered, however, that the strata of Mount Jura having been overturned, the younger are below.

Fossils and age.—Professor Hyatt[a] refers to the Thompson limestone as the *Opis* bed, and remarks:

> Mr. Diller's close and repeated investigations of the stratigraphy have placed the *Opis* bed below the Mormon sandstone in the chronologic series, and my studies, although they led me to incline to the opinion that the fauna was younger, have not succeeded in bringing to light any evidence that can be said to contradict his conclusions. The presence of a large form of *Nerinea* with the columella, showing the typical ridges of the normal forms of this group, indicates that this limestone is not older than the inferior Oolite, and if, as seems to be the case, it is older than the Mormon sandstone, it will probably be proved to be a member of the inferior Oolite.
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> A large species of *Opis* is as abundant in some places as the *Nerinea*, and this genus, which is recorded in Europe as beginning in the Trias, is usually small throughout the lower and middle Jura. The only European species approximating to that of this limestone is the *Opis paradoxa*, as figured by Buvignier, which occurs in the Corallian of the upper Jura. A species of *Terebratula*, apparently identical with the large characteristic species of the Mormon sandstone, also occurs abundantly in this bed. There are also a number of small gasteropods and other fossils requiring further investigation.

MORMON SANDSTONE.

Lithologic character.—The Mormon sandstone consists prevailingly of sandstone, passing on the one hand into conglomerate and on the other into more shaly beds. The most common and characteristic member is a gray compact sandstone so fine that to the naked eye it does not appear granular. Its color becomes brown on weathering, and the rock frequently contains casts of a small *Rhynchonella*. Among the grains of which it is composed there are many of quartz and of feldspar, some of which is clear plagioclase with distinct twinning lamellæ. A few are of pale-green augite, but most of them are of indefinite clouded material in which here and there small lath-shaped crystals of feldspar may be seen, indicating their derivation from igneous rocks. There is a small amount of carbonate of lime present, and it becomes somewhat more abundant in the coarser forms. The conglomerate of the Mormon sandstone is generally greenish, but sometimes reddish. Its pebbles are in a few places mainly quartzite, but at most localities they are chiefly of meta-andesite with a few of metarhyolite, and range from one-eighth of an inch to 18 inches in diameter. Several pebbles of limestone were observed, but none contained fossils. In the conglomerate are masses of fine shaly red sandstone with decided pencil structure parallel to its stratification. This same sort of material occurs also to a limited extent entirely independent of the conglomerate, and in such cases it is thin bedded and finely stratified.

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[a] Bull. Geol. Soc. America, vol. 3, 1892, p. 403.

Distribution and thickness.—The Mormon sandstone, extending across Mount Jura from the lower slopes of Grizzly Mountains to North Arm, occupies a larger area than that of the Hardgrave sandstone and Thompson limestone combined. At both ends it is relatively broad, but in the middle portion it is divided into two belts, one on the west slope and the other near the crest, in positions corresponding to the two belts of Hardgrave sandstone and Thompson limestone.

At a narrow point in the wavy belt across the western slope of Mount Jura the following section was observed: Adjoining the eastern side of the Thompson limestone is 45 feet of massive gray sandstone with a rich fauna. This is succeeded farther up the slope by 30 feet of conglomerate and finally by about 20 feet of finely stratified red shaly sandstone, the "Inoceramus bed" mentioned by Professor Hyatt. The total thickness of this belt a short distance farther south increases to about 225 feet and the conglomerate becomes more prominent, but farther along again diminishes and is scarcely noticeable near the south end.

The crest belt, long and narrow, running south from the summit of Mount Jura is well exposed on the steep slopes facing Hinchman Ravine, and affords the following section: Adjoining the Thompson limestone is a mass of greenish conglomerate 150 feet in thickness. Part of it is coarse and it includes much andesitic material. Some greenish sandstone is interstratified with the conglomerate. Below this is a gray sandstone 400 feet in thickness well characterized by the little *Rhynchonella*. It includes some shaly beds and near the bottom traces of conglomerate. The total thickness, 550 feet at this point, is much greater than that on the western slope of Mount Jura.

The curved area on the lower slopes of Grizzly Mountains opposite the mouth of Hinchman Ravine is chiefly gray sandstone and represents the union of the crest belt and that which crosses the western slope of Mount Jura. Besides the characteristic Mormon sandstone fauna which it contains there are traces of other fossils, and it is possible that some Hardgrave sandstone is here included in the area marked Mormon formation.

The largest area of the Mormon sandstone lies on the north slope of Mount Jura, stretching from the summit to North Arm. It is chiefly gray sandstone but includes also a large amount of conglomerate, which occurs at various horizons in the mass. Near the western border, under the Thompson limestone, there is locally a small amount of conglomerate, in which the fine greenish cement and many of the smaller pebbles are composed almost wholly of andesitic material. Reddish conglomerate and red beds occur in the middle of the Mormon sandstone on the steep slope southeast of Thompson's, but the most important outcrop of conglomerate is nearly a mile farther east, on the edge of the valley about Lucky S road. It strikes N. 27° W.

and dips 62° SW., and the mass is extremely variable in its con position, varying from thin lenses of red shaly sandstone with pron inent pencil structure to coarse conglomerate in which some of tl pebbles are 18 inches in diameter and the material almost wholl andesitic in character.

The only area of the Mormon sandstone yet to be noted is a sma one which is entirely isolated. It occurs about 4 miles northeast (Mount Jura, in sec. 17, T. 26 N., R. 11 E., and contains compa(gray sandstone well characterized by fossils. This mass of the Mo mon sandstone is much more disturbed than the others. The san(stone is much fractured, permeated by small quartz veins, and alon the western border is greatly sheared, producing slickensided slat material.

Fossils and age.—Concerning the fossils of the Mormon sandston(Professor Hyatt,[a] in his paper on the Taylorsville region, reports ε follows:

> This bed contains the remains of a more varied fauna than that of the Hardgra\ sandstone. In some places, especially upon spur 8 of Mr. Diller's map, the fossi are in excellent preservation; but in some localities merely superficial work does n(give good results, the rock being apt to be very friable. Here as elsewhere the grea est treasures await resurrection at the hands of those able to dig deeply into the ston matrix.
>
> It is more difficult to point out the characteristic fossils in this bed than in the Har(grave sandstone. *Lima dilleri* and *L. taylorensis*, *Ctenostreon*, *Trigonia*, and *Entoliur* are apt to occur in all the outcrops. So far as the determination of age is concerne(however, the Ammonitinæ, although not abundant, afford the best evidence. The highly specialized forms, as has been pointed out by several of the most distinguishe paleontologists in Europe, must have been extremely sensitive to the influence of tl changes of the surroundings in passing from one geologic level to another, and ha\ recorded these mutations in their own organizations. Even the encyclopedic Que stedt continually expresses his satisfaction in turning from the uncertain indicatio afforded by the more generalized structures of other mollusca to the decisive chr nologic evidence usually given by the fossils of this group. The list printed belo contains a series of selected species, but many forms, especially among the small(Pelecypoda, which have not yet been studied, are necessarily omitted.

Taylorsville, Cal.	Europe.
Terebratula	*Terebratula perovalis*, Sow., as figured an described by Quenstedt, is similar, b the American species has no dwarfed va eties; inferior Oolite.
Rhynchonella, n. sp	*Rhynchonella quadriplicata*, Zeit., as figure and described by Quenstedt; great Oolit(
Alectryonia, n. sp	*Orthis marshii*, Goldf., as figured by Mor. (Lyc. in Oolite Mollusca; inferior an great Oolite.
Modiola subimbricata, Meek, and also other species of the same genus similar to this, but having shorter and broader shells.	*Modiola imbricata*, Sow., and other speci(of *Modiola*, with heavy umbonal ridge occurring in the inferior and great Oolit(

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[a] Bull. Geol. Soc. America, vol. 3, 1892, p. 403.

Mytilus, n. sp.	*Mytilus sublævis*, Mor. et Lyc., and other species, having arcuate forms and heavy umbonal ridges, which are characteristic of the Oolite.
Pinna cuneiformis, n. sp.	*Pinna cuneata*, Phill., as figured by Mor. et Lyc. in Oolite Mollusca; inferior Oolite.
Pteroperna, n. sp.	Stands between *Pteroperna plana* and *Pteroperna costatula*, Mor. et Lyc.; inferior and great Oolite.
Gervillia, n. sp.	*Gervillia lanceolata* of the upper Lias, but longer and narrower in proportion, and the posterior wing larger. It is in fact a more progressive form in the same series of species than *Gervillia lanceolata*.
Gervillia, n. sp.	*Gervillia aviculoides*, Sow.; great Oolite.
Lima dilleri, n. sp.	*Lima cardiiformis*, Sow.; great Oolite.
Lima, n. sp.	*Lima tenuistriata*, Münst. and Goldf.; inferior Oolite.
Lima taylorensis, n. sp.	*Lima rigidula*, Mor. et Lyc.; great Oolite.
Ctenostreon, n. sp.	*Ctenostreon pectiniformis*, Mor. et Lyc.; inferior and great Oolite.
Pecten, n. sp.	*Pecten disciformis*, Schübl.; inferior Oolite.
Pecten, n. sp.	*Pecten demissus-gingensis*, Quenst.; inferior Oolite.
Pholadomya, n. sp.	*Pholadomya fidicula*, Zeit.; inferior Oolite.
Trigonia, n. sp.	*Trigonia hemispherica*, Lyc.; inferior Oolite.
Trigonia, n. sp.	*Trigonia formosa*, Lyc.; inferior Oolite.
Belemnites, n. sp.	*Belemnites breviformis*, Voltz.; upper Lias to inferior Oolite.
Sphæroceras, n. sp.	*Sphæroceras gervilli;* inferior Oolite.
Grammoceras, n. sp.	*Grammoceras toarcense*, as figured by Buckman; inferior Oolite.
Grammoceras, n. sp.	*Grammoceras leurum*, Buckm.; inferior Oolite.

The fossils indicate the former existence of a fauna which can be provisionally considered as belonging to the upper part of the inferior Oolite.

Inoceramus bed.—Immediately above the Mormon sandstone with its rich fauna there are strata of a red sandstone containing very few remains and these usually in poor condition. Three species of fossils were found in them: A *Terebratula*, apparently the same as that occurring so plentifully in the typical Mormon sandstone; two fragments of a large species of *Inoceramus;* and a fragment of an ammonite of the genus *Perisphinctes*. The *Inoceramus* of the Jura is not so large in the Lias as in the Oolite, and these fragments appeared, therefore, to have belonged to shells at least as old as the Oolite. The specimen of the *Perisphinctes* may prove to be identical with some species found below. It is probable, therefore, that this bed belongs, as in fact is indicated by the geology, to the upper part of the Mormon sandstone. On the other hand, the fact that one out of the three species was new to the fauna of the Mormon sandstone justifies a provisional separation under a different title on biologic grounds. Even if not sustained by future work, this distinction will serve a good purpose if it succeeds in calling the attention of collectors in the same or other localities to facts that might otherwise escape their notice.

Relation to adjacent formations.—The Mormon sandstone is in conformable contact with the Thompson limestone, though it marks a decided change in the character of the sediment from fine calcareous to coarse fragmental derived chiefly from altered andesitic rocks. This relation may be best seen on the southwest slope of Mount Jura near Donnerwirth's, where the positions of both the above-named formations are practically parallel to that of the adjacent Hardgrave sandstone.

The isolated mass 4 miles northeast of Mount Jura rests unconformably upon the Hosselkus limestone, as shown in fig. 6, without the intervening Triassic and Jurassic strata. This discordance, however, is not of deposition but of dislocation along a line of extended faulting.

The relation of the Mormon sandstone to the later formations will be considered in connection with the Bicknell sandstone.

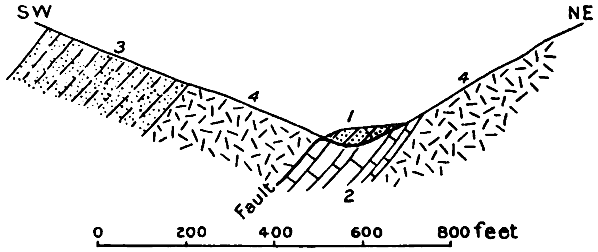

FIG. 6.—Relation of Mormon formation to Hosselkus limestone. 1, Mormon sandstone; 2, Hosselkus limestone; 3, Robinson formation; 4, eruptive rocks.

BICKNELL SANDSTONE.

Lithologic character.—The Bicknell sandstone is composed chiefly of red and gray sandstone associated with some dark shales and tuffaceous beds. The dark brownish-red sandstone is largely feldspathic and contains much red oxide of iron with more or less carbonate of lime. It somewhat resembles the red Hardgrave sandstone, but is darker colored, and though much of its material may be derived from igneous rock, its particles are not characterized by the presence of numerous small crystals of feldspar as in the Hardgrave sandstone. Sandstones, mottled gray and red, form transitions to the gray sandstone which is the most abundant rock of the formation. Much of it is fine dark bluish gray, very compact and hard, breaking with a conchoidal fracture, and flecked here and there by small particles of pyrite. It looks so much like hornfels that one is surprised to find it locally full of large shells. Associated with this form is more or less black shale, some beds of which weather white and look like fine volcanic dust. A thin section, however, shows no characteristic volcanic material, but instead extremely fine sediment with a multitude of minute microscopic crystals of rutile which have developed in the sediment since it was laid down.

A coarser variety of the sandstone is light gray or greenish and passes into a rock which is full of small white crystals of feldspar with a few scales of gray mica embedded in a dark groundmass, and the general aspect is decidedly igneous. The fact that it contains distinct fossils shows that it is fragmental, and it locally becomes coarse, so that its real character is more evident. In thin section under a microscope the fine fossiliferous rock is clearly fragmental, and much of the sediment was evidently derived from the erosion of volcanic rocks.

Distribution and thickness.—The Bicknell sandstone is much more regular in its distribution than the other Jurassic formations already noted and forms a continuous belt from the mouth of Hinchman Ravine across the east and north slopes of Mount Jura to North Arm of Indian Valley. Its greatest development appears to be on the southeast slope of Mount Jura, which is the only portion that is well characterized by fossils.

The reddish sandstone is the earliest portion of the Bicknell sandstone and lies near the west border of the mass. It is best exposed along the crest north of the summit. The compact fine dark-gray sandstone with the black shaly portions interbedded with gray sandstone forms the middle portion of the mass and becomes more tuffaceous along the east border where it adjoins the Hinchman standstone.

The thickness of the Bicknell standstone on the southeast slope of Mount Jura, where its greatest development occurs, is probably over 1,000 feet. From this point it appears to decrease in magnitude to the north and south so as to average less than 500 feet in thickness.

The general attitude of the Bicknell sandstone is like that of the Hardgrave, Thompson, or Mormon formations already noted. With but few exceptions it strikes west of north and dips southwest beneath Mount Jura.

Fossils and age.—In this sandstone fossils are neither so generally distributed nor so abundant as in the other Jurassic formations already noted. None have been found north of the summit of Mount Jura. Regarding this Professor Hyatt[a] says:

> The fauna of the Bicknell standstone is not so rich in species as are the Mormon and Hardgrave sandstones and the Thompson limestone, nor are the fossils so plentiful. The character of the rock in the surface exposures found by the party made it almost impossible to get out large specimens in perfect condition. Nevertheless, a sufficient number of molds of several large species of *Trigonia* (*T. obliqua* and *T. plumasensis*) and some well-preserved specimens of *Gryphæa bononiformis* were secured, all of which are more or less characteristic of the youngest faunas of the Jura in Europe.
>
> The remains of the Ammonitinæ are fragmentary, but those that were found certainly indicate a somewhat older fauna than the species above named. There are a number of the molds *Rhacophyllites* with the internal septa partly preserved, a fragment of a *Reineckia*, two rather poor molds of *Macrocephalites* (?), and several fragments of *Perisphinctes*. These form an association which gives strong support to the provisional opinion that the fauna is really synchronous with that of the Callovian, the oldest

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[a] Bull. Geol. Soc. America, vol. 3, 1892, p. 406.

fauna of the upper Jura, or Malm, in Europe. The specimens of *Chemnitzia* are molds of a very large shell, but unluckily do not show the aperture. The only species in Europe which appears to be a close ally of this is also from Callovian.

The list below gives a very inadequate idea of the fauna, since none of the belemnites or Ammonitinæ can be directly compared with European species on account of the need of more perfect specimens and are, with one exception, not mentioned. There are also a large *Nerinea* and a few species of Pelecypoda and Brachiopoda, which were not considered important in this preliminary notice.

Taylorsville, Cal.	Europe.
Gryphæa bononiformis, n. sp.	*Ostræa bononiæ*, Sauv., as figured by de Loriol et Pellat; Portlandian.
Entolium costatum, n. sp.	
Oxytoma, n. sp.	
Trigonia obliqua, n. sp.	*Trigonia michelloti*, de Loriol; Portlandian.
Trigonia plumasensis, n. sp.	*Trigonia lusitanica*, as figured by Choffat; Portlandian.
Trigonia naviformis, n. sp.	*Trigonia navis;* inferior Oolite.
Chemnitzia, n. sp.	*Chemnitzia athleta*, d'Orb.; Corallian.
Rhacophyllites, n. sp.	

The group of *Trigonia glabræ* to which *T. obliqua* belongs reached its acme in the Portlandian, the species being both rare and comparatively small in the Lias and inferior Oolite. *T. obliqua* is of extraordinary size and shows the incomplete costæ of the Portlandian species. The group of *Trigonia* to which *T. plumasensis* belongs is very peculiar in the characteristics of the costæ and the ornamentation of the anal area, and it has hitherto been represented in Europe only by the unique form, *T. lusitanica*, found only in the highest Jura of Portugal. Besides these two large species there is also in *T. naviformis* an equally large representative of another peculiar and hitherto unique style of ornamentation. This, as its name implies, is similar to *T. navis* of the inferior Oolite in Germany, a species hitherto considered to be the only representative of a very distinct group, the *Trigonia schapoidæ*, and having a pattern of costation not found in any other species (except *T. naviformis*) and a narrow chorologic range.

The group of the *Trigonia undulatæ* is represented by a species also of extraordinary size, but the *Trigonia clavellatæ*, the group more largely represented than any other in the inferior Oolite (if one can judge from the simple specimen obtained in the Bicknell sandstone) is not materially modified.

Bicknell tuff.—Above the sandstone and in immediate contact with it is a tuff described by Mr. Diller, which contains in part the same species as the sandstone, and the fossils indicate the same fauna. Nevertheless, it should be noticed that it contained no remains of *Trigonia*, and that the fauna has not been critically examined.

Relation to adjacent formations.—As to the relation of the Mormon and Bicknell sandstones, observations are not so definite, though they point to conformity. Upon the south slope of Mount Jura, as well as upon its north end, the two sandstones are separated by a belt of meta-andesite, but for nearly a mile north of the summit they appear to be in conformable contact. The actual contact was not observed, but throughout the two formations appear in parallel position. The adjoining formations are connected by transitional sediments and there is no decided interruption visible between them excepting a change in fauna.

HINCHMAN SANDSTONE.

Lithologic character.—The Hinchman sandstone is composed essentially of coarse sandstone with shaly parts and some conglomerate which is generally fine and derived chiefly if not wholly from andesitic rocks. Much of it is decidedly tuffaceous. The most common form is greenish gray and contains darker colored shaly patches, but is not conspicuously fragmental. Examined microscopically it is found to be made up largely of fragments of feldspar, augite crystals, and varying proportions of andesitic rock, fragments of which are clearly microporphyritic. The feldspar is generally much altered. Some of the augite is fresh, but most of it is altered to chlorite, giving a greenish color to the rock. It is never coarse like volcanic agglomerate, though it is sometimes made up largely of ejected volcanic material, some of which is clearly pumiceous. The grains are rarely well rounded by attrition, though it is evident that they have been transported and loosely aggregated on the sea floor, affording corners and cavities where corals, belemnites, and a number of other marine forms flourished. Remains of these animals are not confined to one horizon, but are scattered throughout the formation. The conglomerate locally becomes coarse and composed of pebbles, some of which are well rounded; others are angular. The largest pebbles are rarely a foot in diameter. One of the most abundant types is a reddish, decidedly microporphyritic andesite. Others less common are dark and macroporphyritic, with either feldspar or hornblende phenocrysts. Limestone pebbles or nodules occur sporadically, but none could be found with fossils.

Distribution and thickness.—The outcrop of the Hinchman sandstone is confined to the slopes of Mount Jura, and stretches in one continuous belt from the mouth of Hinchman Ravine to the borders of North Arm. Like the other formations of Mount Jura its general strike, without much variation, is a few degrees west of north and its dip to the southwest. Its best exposures are at Curtice Cliff, in the lower part of Hinchman Ravine, where most of the fossils were collected, though they occur also along the crest on the northern slope. The greatest variation from the normal Hinchman tuffaceous sandstone occurs in the coarse conglomerate with well-rounded pebbles along the west slope of South Fork of Foremans Ravine. This conglomerate somewhat resembles that of the Mormon formation exposed by the Lucky S road on the flat near Foreman and its strike appears to connect it with that mass. No fossils could be found in it, and the stratigraphy of the west slope of the South Fork of Foremans Ravine places it in the upper part of the Hinchman sandstone as here considered. This conglomerate ranges from 50 to nearly 200 feet in thickness and was not recognized in Hinchman Ravine, where the tuffaceous portion of the formation has its greatest development and attains a thickness of 500 feet.

Fossils and age.—The most widely distributed and characteristic fossils of this horizon are corals which Professor Hyatt relegates to the genus *Stylina* and has designated the bed in which they occur "*Stylina* bed." He reports further[a] in the paper previously referred to that—

> The presence of the same species of *Rhacophyllites* as that found in the Bicknell sandstone indicates the continuity of the fauna of this bed with that of the preceding; but, on the other hand, the absence of *Trigonia* and the presence of close allies of *Ostræa bruntrutana* and of *Pecten suprajurensis*, shows that we have ascended in time to a younger fauna. The abundance of corals of the genus *Stylina*, these being the most widely distributed and characteristic fossils of the Hinchman tuff, shows that the age is probably that of the Corallian. In Europe these corals are rare in the Oolite, but reach their acme in numbers of species and forms in the Corallian of the upper Jura. The opinion expressed with regard to the age of the Bicknell sandstone is greatly strengthened by this fact, and it also adds to the evidence that the subdivisions of the Jura in North America and in Europe, like those of the Trias, may be compared much more closely than one would at first suspect from the extremely fragmentary records heretofore found in this country.
>
> The fossils occurred in patches and, although abundant, good specimens were not easily obtained. The list is as follows:

Taylorsville, Cal.	Europe.
Gryphæa curtici, n. sp	*Ostræa bruntrutana*, as figured by de Loriol; Corallian to Portlandian.
Camptonectes bellistriatus, Meek	*Pecten suprajurensis*, Buvignier; Kimmeridgian.
Chemnitzia	*Chemnitzia athleta*, d'Orb.; Corallian.
Rhacophyllites (same species as in the Bicknell sandstone).	
Stylina tubulifera	*Stylina tubulifera*, Ed. et H.; Corallian. *Astrea tubulifera*, Goldf.; Corallian.
Stylina subjecta, n. sp	Closely allied to a specimen in Museum of Comparative Zoology named *S. echinulata*, Lmk.; Corallian.
Stylina alba, n. sp	
Stylina minuta, n. sp	Resembles the Cretaceous species figured by Goldfuss as *Astrea geminata* (equal *S. geminata*, Ed. et H.), but septa are not so symmetrical.
Stylina intermedia, n. sp.	
Stylina tertia, n. sp.	

> Two species of *Belemnites* and a number of gasteropods, pelecypods and brachiopods were also found in this bed.

Relation to Bicknell sandstone.—The Hinchman and Bicknell sandstones are conformable and connected by intergradation, so that, though the Bicknell sandstone is prevailingly fine and the Hinchman prevailingly coarse tuffaceous sandstone, there is no sharply traceable boundary between them. The general lithologic differences, in addition to the faunal contrasts pointed out by Professor Hyatt, furnish sufficient grounds for distinction. Nevertheless, these two formations have greater similarity than any other two of Mount Jura.

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[a] Op. cit., p. 407.

FOREMAN FORMATION.

Lithologic character.—The Foreman formation is a succession of shale, sandstone, and conglomerate in which the sediment is for the most part derived from rocks which are not clearly volcanic. The shales are often slaty and locally have "pencil structure," and range in color from dark carbonaceous with traces of leaves through gray, which predominates, to shades and tints of red and yellow. A remarkable feature of the shales locally is their pencil structure, which is particularly well developed in the summit of Evans Peak. The beds of red and gray sandy shales making the summit of the peak break up into small columns, often of lead-pencil size, but generally smaller. They are less commonly larger, reaching a maximum length of 7 inches and a diameter of about half an inch. The pencils are commonly four sided and diamond shaped or rhombic in cross section, but occasionally they have three or five sides.

Almost as abundant as the shales are the sandstones, most of which are very fine and decidedly shaly. They are reddish brown and gray, sometimes mottled with darker spots, chiefly carbonate of lime. These spots weather out more easily than the other parts and leave the rock with occasional holes in its surface. Occasionally the gray sandstone is more siliceous and contains irregular particles which give to the mass the appearance of a fine tuffaceous conglomerate.

Conglomerate is less abundant than either shale or sandstone and is usually in thin beds of small extent scattered throughout the formation. The most characteristic conglomerate of this formation is composed almost wholly of small pebbles of cherty quartz, black and gray in color, and rarely over half an inch in diameter. Of this there are but few beds ranging from 5 to 12 feet in thickness. A more abundant form of conglomerate contains locally many shale fragments and well-rounded pebbles chiefly of meta-andesites and rhyolites, with a few of fossiliferous limestone. The majority of the beds are small and are made up of small pebbles, rarely as large as 3½ inches in diameter. Associated with the limestone pebbles in the conglomerate are concretionary nodules of carbonate of lime, which occur also in the shale and sandstone. They do not contain fossils and grade into the inclosing rock instead of having a sharp contact, as is the case with the limestone pebbles.

Distribution and thickness.—The Foreman formation occupies a larger area than all the other Jurassic formations of that region combined, and extends from Genesee Valley northwest to Mountain Meadows, a distance of 13 miles. Two interruptions occur in the belt, one near Hinchman Ravine by meta-andesite, and the other at North Arm, where it is covered by alluvium. At the northwest end of the exposure the Foreman beds disappear in the same way by passing beneath the alluvium of Mountain Meadows and the lavas of the great volcanic field beyond. The small area on the border of North Arm, a mile north of Peters Creek, is the edge of a large connecting mass which underlies the alluvium of North Arm, but the two small areas, one on Lights Creek and the other on Surprise Creek, are entirely isolated. Though the formation is composed of interstratified shale, sandstone, and conglomerate throughout, these rocks are so distributed that the formation may be roughly divided into three members of about equal thickness. The upper or oldest member, along the west border of the formation, is composed very largely of dark shale with a few beds of fine cherty quartz conglomerate and contained nearly all the fossils thus far collected from the formation; the middle member is chiefly gray sandstone with a few traces of fossils, while the lower or youngest member, lying along the east border, is made up largely of gray shales and as far as yet known is without fossils.

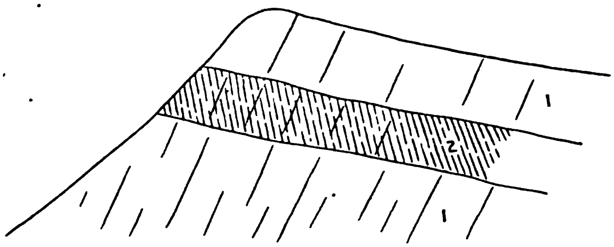

FIG. 7.—Section of interbedded shale and sandstone of Evans Peak, showing relation of joint and pencil structure. 1, Jointed structure of sandstone and shale; 2, pencil structure of shale.

The Lucky S road affords a good section of this formation, especially of the cherty conglomerates, in its older portion near the western border, but the most continuous exposures occur on the steep slopes of Evans Peak, where 1,600 feet of strata outcrop. All three members are well exposed in the Evans Peak section, and shales predominate, interstratified with sandstone and numerous layers of conglomerate. As already noted, the shales are remarkable for their highly developed pencil structure. The shales dip to the southwest and are cut by joints having about the same strike and a somewhat steeper dip to the northeast. The joint planes are usually very rough, due to the impinging of the pencils, which are vertical. The general relations of the stratification to the jointing and the vertical pencils are shown in fig. 7, and the plan of the pencil-making fissures on the plane of stratification in fig. 8. The planes bordering the pencils are not clearly slickensided, and yet they may have been planes of motion to produce the several sets of slaty cleavage which divide the mass

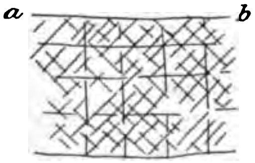

FIG. 8.—Plan of pencil structure on plane of stratification. a–b, Strike.

into pencils. The pencil structure of the sandy shales, although best developed on the slopes of Evans Peak, occurs on Peters Creek and elsewhere locally in the finer sediments of the Robinson beds, as well as in the formations of Mount Jura.

Fossils and age.—Fossil plants were discovered near Foreman in dark shale close to the west border of this formation by Cooper Curtice in 1890, and at a later date the small collection was somewhat enlarged by E. G. Paul and James Storrs. Professor Fontaine studied the collection and described[a] the plants, and his conclusions are as follows:

> The plants are very fragmentary, and most of them are poorly preserved. The most distinct are a small *Equisetum* and several ferns with small pinnules. The ferns are the most numerous, but unfortunately they present mostly such portions as the tips of pinnæ and detached fragments of pinnæ. The amount of material is not sufficient to enable one to determine with positiveness their relations to previously described forms, for ferns are so notoriously variable in foliage that a considerable amount of material is needed to make reliable determinations. Still, taking the collection as a whole, and looking to the nearest relationships with previously known fossil plants, we may arrive at some results with a considerable degree of certainty.
>
> The plants are certainly younger than Paleozoic, and as the elements of the flora are ferns, equiseta, cycads, and conifers, with no trace of dicotyledons, they are Mesozoic, most probably older than Cretaceous, with the possible exception of its very base.
>
> Owing to the imperfection of the material and the absence of the type forms, I can not come to a positive conclusion as to the exact position in the Mesozoic of these plants, but I think the weight of evidence is strongly in favor of the flora being Rhætic or uppermost Trias.

In a paper on the geology of the Taylorsville region of California,[b] the Foreman beds, on the evidence afforded by the plants, were relegated to the top of the Triassic. At that time only a few traces of fossil animals were known in the Foreman beds. A belemnite, a gasteropod, and a cast of a bivalve shell, with traces of plants, had been found about a thin layer of dark bluish limestone at the head of Starks Ravine, near the south line of sec. 35, T. 27 N., R. 10 E., about 3 miles southeast of Evans Peak.

Further collections of fossil plants were made at the same locality by James Storrs in 1904 and submitted to F. H. Knowlton, who reports as follows:

Acrostichites ? princeps (Presl.) Schenk.
Acrostichites brevipennis Ward.
Sagenopteris ? sp.
Equisetum munsteri (Stb.) Brongn.
Podozamites ? sp.?
Conifers ? fragments.

> These determinations are based on Fontaine's identifications of the earlier material from the same locality, as recorded in Ward's Status of the Mesozoic Floras, First Paper, pages 333, 334. I have not looked far enough into the question to have an opinion as to the bearing of these plants on the age, but I may say, after looking rather hastily over the earlier material, that I incline to question several of Fontaine's generic determinations. His *Podozamites ? taylorvillensis* is certainly a *Pterophyllum*, his *Sagenopteris* looks to me like *Glossopteris*, and his *Acrostichites* may prove to be *Gleichenia* or *Gleichenopsis*. (February 8, 1905.)

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[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 333.

[b] Bull. Geol. Soc. America, vol. 3, 1892, p. 373.

The discovery of shells at a new locality in this formation by James Storrs in 1904 affords more important data for reference to a definite horizon. The shells occur in the older portion of the formation, near the plant beds, in approximately the same horizon as those of Starks Ravine. They were studied by T. W. Stanton, who reported January 20, 1905, as follows:

> The fossils were compared with the earlier collections from the same region studied by Professor Hyatt, and it was thus practicable to confirm Mr. Diller's field determinations of horizons, although in most cases the fossils are not specifically identified because the species have not been described.
>
> The only important change in our ideas concerning the relations of the various Mesozoic formations of the region is caused by the collection from the Foreman beds (No. 6776). This formation has previously yielded only a few fragmentary plants which were supposed to be Upper Trias (Rhætic). The present collections of marine invertebrates is sufficient to prove that at least a part of the formation is Middle Jurassic or later.
>
> The following lists, with brief comments, will indicate the character of the collection from each locality:
>
> 6776. South fork of Foremans Ravine, 3 miles northeast of Taylorsville.
>   Pecten sp.
>   Trigonia naviformis Hyatt ?...Fragments of this or a closely related species.
>   Astarte sp.
>   Perisphinctes ? sp............Imprint.
>   Ammonites..................Imperfect imprints of two genera.
>   Belemnites..................Imprint.
>   Several undetermined small pelecypods and gasteropods, represented by casts and imprints.
>
> This lot differs lithologically and in general faunally from any of the known fossiliferous horizons of the Taylorsville Jurassic.
>
> The *Trigonia* is convincing evidence that the bed from which it came is later than the Triassic, and the close relationship, if not identity, of this *Trigonia* with *T. naviformis*, as well as the character of several of the other forms, indicates that the horizon is in the Jurassic and later than the Hardgrave sandstone—possibly later than the Bicknell sandstone.

In reply to my question as to the faunal relation of these beds to the Hardgrave sandstone, Stanton stated that they may well be the youngest Jurassic beds of the region, even younger than the Hinchman. This statement of Stanton is confirmed by the stratigraphy of the region, which places the Foreman beds next younger than the Hinchman sandstone.

Relation to adjacent formations.—The general strike of the Foreman beds is northwest and the dip is to the southwest immediately beneath the Hinchman sandstone and all the other formations of Mount Jura which have been overturned. The contact between the Foreman and Hinchman strata is locally very irregular along the east side of Hinchman Ravine, and the lack of accord in the strikes of the two formations suggests a slight unconformity. Completely satisfactory evidence on this point could not be obtained, though it is supported by the fact that in the hills just east of Foreman the

Foreman beds unconformably overlap the Mormon formation without the intervening Bicknell and Hinchman sandstones. Farther northwest, beyond North Arm, the Foreman beds come in direct contact with the metarhyolite and the Robinson formation without any intervening Jurassic and Triassic strata. Northeast of Mount Jura, at the head of South Fork of Foremans Ravine, the Foreman beds unconformably overlap the Peale formation of Carboniferous age but do not come in contact with any other sediments in that locality.

As bearing upon the unconformity between the Foreman beds and the Carboniferous formations, it may be noted here that fossiliferous limestone pebbles were found in the conglomerate of Evans Peak. In them Girty reports *Diphyphyllum* sp., *Amplexus?* sp., and *Archæocidaris* sp., and remarks that they are "certainly Paleozoic and probably Carboniferous."

SOUTHERN EXTENSION OF THE TRIASSIC AND JURASSIC ROCKS OF THE TAYLORSVILLE REGION.

The Mesozoic formations of the Taylorsville region are cut off by igneous rocks before reaching the fortieth parallel. Next south of that line is the Downieville quadrangle, which has been mapped and described in a folio by H. W. Turner. He recognizes two formations in the "Juratrias." The lower he regards as closely related to the Sailor Canyon formation, and the upper he designates the Milton formation. The distribution of these two formations, as far as it has been possible to separate them, is shown in Pl. I.

SAILOR CANYON FORMATION.

The lower portion is composed chiefly of siliceous argillite with some coarser sediments in part volcanic, and a layer of fine breccia of gray fragments in a dark matrix which contains radiolarian remains. An ammonite was found in the siliceous slates, which shows that they are closely related to the Sailor Canyon beds which Waldemar Lindgren discovered in the Colfax and Truckee quadrangles south and southeast of Downieville.

According to Lindgren black calcareous shale without pronounced fissility, interbedded with subordinate strata of quartzite and limestone possibly to the thickness of 6,000 feet, is well exposed with easterly dip along North Fork of the American River in the neighborhood of New York and Sailor Canyon, where the lower part contains numerous imperfect ammonites and shells of *Daonella* and *Monotis*. The basal bed is a closely packed conglomerate of chert and slate, and all the relations observed on the American River Lindgren thinks "point strongly to an unconformity between the Juratrias and the Carboniferous."

The fossils and the lithology of the Sailor Canyon beds on American River at once suggest the Swearinger formation to any one familiar with the Taylorsville region, but this may be deceptive. Professor Hyatt, who has made a thorough study of the fossils from both localities, remarks[a] that "the entirely distinct species of the two localities, even in the genera *Monotis* and *Daonella*, show that there were two distinct faunal areas, and that there could have been no communication between them during the time of the deposition of the *Monotis* and *Daonella* beds, even if it is admitted that they were contemporaneous in deposition, an opinion which can not be maintained by any facts now known."

MILTON FORMATION.

Turner describes the formation as made up "largely of tuffs, all of which, being evenly stratified, present the appearance of having been laid down in water. These beds contain igneous fragmental (pyroclastic) material of the augitic greenstone series, quartzite, fine red slates, a little marble, and a variegated breccia or conglomerate." The limestone contains garnet and wollastonite and the sandy sediments brown mica developed under the metamorphosing influence of the adjacent granitic intrusions. The Milton formation, Turner states, is distinctly later in age than the siliceous slates (Sailor Canyon) and are probably Jurassic. A comparison with the Taylorsville section suggests that they may be the equivalent of the Trail formation, which is of fresh-water origin and contains much pyroclastic material with other sediments and few fossils.

In the northwest portion of the Truckee quadrangle masses of diabase and diabase porphyry intercalated in the slates and tuffaceous rocks are of frequent occurrence, and Lindgren suggests that they may be the Milton formation.

On the general geologic map of the Lassen Peak region and the northern end of the Sierra Nevada the Sailor Canyon beds are mapped as Triassic and the Milton as Jurassic. Lindgren and Turner pointed out that these rocks are much less compressed than those of Paleozoic age. These Mesozoic rocks dip eastward and appear to be conformable throughout, but rest with marked unconformity upon the Carboniferous rocks.

A short distance east of the area covered by the general map (Pl. I), in western Nevada, are a number of localities at which fossiliferous Triassic and Jurassic strata have been found. The most important Triassic areas are a few miles southeast of Dayton, near Volcano, 30 miles northeast of Walker Lake, at New Pass in the Desatoya Mountains, and especially at Star Peak near Humboldt, a locality made famous by the work of the Fortieth Parallel

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[a] Bull. Geol. Soc. America, vol. 5, 1894, p. 399.

Survey. At all of these localities the fossils indicate, according to Professor Hyatt[a] and James P. Smith,[b] a horizon lower than the Hosselkus limestone, about the position of the Pit shales so well exposed in the Redding quadrangle. Lindgren has shown[c] that in northeast Oregon and the adjoining portion of Idaho the Triassic, like that of the Taylorsville and Redding regions, is well developed, suggesting connection with the great masses of British Columbia. At Soda Springs, Idaho, about 100 miles north of Ogden, a still lower horizon of Triassic occurs. It is the oldest known in the Nevada basin region. This basin contains also Jurassic strata. As shown by Hyatt, the fauna of the Hardgrave formation of Taylorsville occurs at Volcano, 30 miles east of Walker Lake in Nevada, and at Bear Creek in the Blue Mountains of eastern Oregon, and he asserts[d] that "it is obvious that there was no barrier between these three littoral faunas at the time of the deposition of the upper Lias of Taylorsville and that the three basins were contemporaneous and connected."

RELATION OF THE TAYLORSVILLE JURASSIC TO THE MARIPOSA.

The latest conclusion of Professor Hyatt concerning the relative age of the Jura-Triassic rocks of the Sierra Nevada[e] places the Hinchman formation about the middle of the upper Jurassic next older than the Mariposa formation that lies toward the base on the west slope of the Sierra Nevada. He remarks the distinctness of their faunas. The areal relation of the two formations at their nearest approach is shown on the general map, Pl. I. The fauna of the Foreman beds had not been discovered when Professor Hyatt wrote, and it seems very probable that a thorough study of it by a paleontologist in the field may bring the Foreman beds, the latest Jurassic of the Taylorsville region, and the Mariposa still closer together.

The Mariposa formation outcrops on the western slope near the foot of the Sierra in several long, narrow areas approximately parallel to the range. To the northwest of Mariposa, one belt of exposures ends near Folsom and the other near Colfax. Farther in the same direction, near Oroville, some black slates containing a remarkable flora have been called Monte de Oro formation by Turner.[f] Their lithologic similarity to the Mariposa is striking and their flora is thought by the paleobotanists to indicate about the same horizon.

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[a] Bull. Geol. Soc. America, vol. 5, 1894, p. 400.

[b] Jour. Geology, vol. 6, 1898, p. 778.

[c] Science, new ser., vol. 13, 1901, p. 270.

[d] Op. cit., p. 401.

[e] Op. cit., pp. 412–413.

[f] Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 548. A fuller account of this formation is in course of publication by the present writer in the Bulletin of the Geological Society of America, vol. 19.

In these plant beds, however, some invertebrate fossils have been recently discovered by James Storrs and they throw new light on the age. Concerning Storrs's collection T. W. Stanton reports (February 3, 1908) as follows:

> About a year ago, in reporting on another collection obtained by Mr. Storrs from these beds, I expressed the opinion that they are Jurassic, and older than the Mariposa beds. The fossils now under examination add several species to the previous list, although I am still unable to assign them to described species, and they do not therefore afford a good basis for correlation with well-established horizons. Perhaps the most important addition is the form doubtfully referred to *Aucella*. It is represented by one fairly good valve and a fragment of another which might belong to either *A. piochi* of the Knoxville or to *A. erringtoni* of the Mariposa as far as can be determined from the features preserved. Unfortunately there is no right valve in the collection, and the generic reference is not positive. If it is really an *Aucella*, the age of the beds is either Mariposa or Knoxville, more likely the former. The general character of the other forms is suggestive of the older faunas of the Taylorsville region, but it must be admitted that there is no definite evidence of this.
>
> The following list mentions the forms distinguished:
>
> Ostrea sp.
>
> Pecten. Two or three species.
>
> Aucella? Imperfect specimens with the form of *A. piochi* or *A. erringtoni*.
>
> Modiola sp.
>
> Trigonia sp.
>
> Cardium? sp. This is an abundant species that in a previous report was thought to be an aviculoid shell and doubtfully referred to *Eumicrotis*. The specimens of the present collection are somewhat better preserved, but the generic reference is still doubtful.
>
> Belemnites sp. Several fragments.

SUPPOSED MARIPOSA IN NEVADA.

In western Nevada, according to King,[a] a thickness of probably 4,000 feet of fine-grained argillaceous slates overlies the Jurassic limestone, and he says: "It is quite clear that these upper Jurassic slates are to be correlated with the similar rocks in California." Later researches have not yet thrown definite light upon the above correlation except that it now seems possible and perhaps probable that the slates of western Nevada may be equivalent, at least in part, to the Foreman beds of the Taylorsville region.

TERTIARY.

AURIFEROUS GRAVELS.

GENERAL STATEMENT.

The auriferous gravels outlined in the maps of the Taylorsville region are deposits of an ancient system of drainage, in Tertiary time, very unlike that of the same region to-day. The principal ancient stream, Jura River, had its source in the high Sierra summits, possibly west of the main crest, in the neighborhood of English Mountain, as shown in Pl. I, and flowed in general a little west of north, by the Cascade mine, across the Downieville quadrangle and the Mount Jura divide, in the Taylorsville region, to the northern end of the Sierra Nevada, beyond Indian Valley, where it entered a larger body of water and formed the main mass of auriferous gravel, one of the most extensive deposits of its kind in California.

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[a] Systematic geology: U. S. Geol. Explor. 40th Par., vol. 1, 1878, p. 295.

AURIFEROUS GRAVELS OF JURA RIVER CHANNEL.

Mount Jura divide.—The divide extending northeast from Mount Jura toward Kettle Rock has four areas of auriferous gravels, as shown in Pl. III, and preserves a cross section of the ancient valley once occupied by Jura River. The two largest of these masses have been mined at Taylor and Hull diggings and range in altitude from 5,300 to 5,600 feet. One of the smaller areas near the west side extends down to 5,100 feet, but this may be due in part to a landslide; the other lies at an altitude of 6,000 feet on the east side of the valley. In all probability these four areas were once connected, forming a continuous mass for approximately 5 miles along the divide.

Taylor diggings.—Taylor diggings, a mile northeast of the summit of Mount Jura, were operated years ago by a ditch from Taylor Lake, near Kettle Rock, and expose about 100 feet of gravel, at the bottom of which lies a bed of impure lignitic coal about 5 feet in thickness. Prospect tunnels have been run into this bed for a short distance to the west and south and about a ton of coaly material removed and tried for blacksmithing. The coaly material lies on Jurassic bed rock and is overlain by gravel, varying in size, but throughout a thickness of 100 feet rarely as much as 6 inches in diameter. The pebbles are chiefly metarhyolite, like the rock so well exposed along the eastern slope of Grizzly Mountains. The remaining pebbles are for the most part granite and basic igneous rocks, some of which are rich in pyroxene.

Hull diggings.—On the Lucky S road is a flat-topped mass of gravel capping the divide and main spur for over 3 miles. At the head of the north fork of Hosselkus Creek, Hull diggings expose about 100 feet of gravel, in the upper portion of which there are 15 feet of fine sand and gravel. The coarser gravel above and below contains pebbles rarely as large as a man's head. Toward the bottom there is much sand and bowlders of metahornblende-andesite porphyry unlike the meta-andesite bed rock, and some of the bowlders are 5 feet in diameter. Whether these bowlders occur sporadically in the sand or form a distinct layer could not be determined for lack of definite exposure. No bowlders occur in the well-exposed upper half of the deposits. Similar bowlders occur along the borders of the exposed areas where the gravel has been removed and has brought the bowlders to the surface. Farther southwest toward Taylor diggings a number of granite bowlders occur with the others, and it is evident that all came out of the gravel deposit.

The small mass of gravel on the Lucky S road, 2½ miles east of Hull diggings, is fine and contains many dark pebbles like hornfels. No bowlders were observed. The gravel, although well rounded, differs considerably in composition from that farther west, and it is possible that this deposit belongs to a side stream.

The gravels of the Mount Jura divide contain no pebbles of the Tertiary lavas which lie to the east and northeast. Many pebbles of igneous rocks are present, but they are all of types that belong to the pre-Tertiary bed-rock series.

Peale diggings.—Following up the Jura River deposits south from Taylor and Hull diggings, we come to three flat-topped masses of gravel at an elevation of from 5,500 to 5,800 feet capping the divide between Wards Creek and Little Grizzly Creek, southwest of Genesee Valley. Peale diggings in these masses expose about 100 feet of gravel, in which pebbles of old rhyolite or quartzite like those of Grizzly Mountains are most abundant. There are some of darker igneous rock and a few of granite. Pebbles 6 to 10 inches in diameter are common, but bowlders as large as 2 feet in diameter are rare.

In the gravel bars of the present streams of the Taylorsville region, and in fact along all streams with fairly strong grade, it may be observed that the somewhat flattened pebbles instead of lying horizontal are generally inclined so that they lean downstream, and, like shingles of a roof, overlap in that direction. Their upper surfaces slope upstream. This is their position of greatest stability against stream erosion and shows the direction of flow in the stream making the deposits.

At the Peale diggings most of the pebbles are approximately spherical, but a few are somewhat flattened and generally slope southward, showing that the stream came from that direction. The fact that the pebbles are largely of quartz porphyry, like that of Grizzly Mountains, from which the stream came, points to the same conclusion.

Cascade mine to Mohawk Valley.—The facts of the country south of the fortieth parallel are drawn largely from the publications of Turner and Lindgren. In the Downieville folio, page 4, Turner has traced the deposits of the ancient stream we are following from 2 miles southeast of Tower Rock southward, by way of the Cascade mine, Lava Peak, and Mohawk Valley, to Haskell Peak and beyond in the crest of the main divide between Mohawk Creek of Feather River and North Fork of Yuba River.

At the Cascade mine sandy layers are interstratified with gravel, and the total thickness of the deposits is 325 feet, at an elevation of about 6,000 feet. There are large granite bowlders in the gravel and the bed rock belongs to the auriferous slate series, cut by numerous dikes. The occurrence of granite bowlders to the north of their source, though but a short distance, Turner thinks may be regarded as evidence that the stream flowed to the north. The Cascade mine gravel lies on the edge of a great mass of andesitic breccia, beneath which it extends southward, to reappear on the slopes of Little Long Valley Creek at an altitude ranging from 6,000 down to 5,000 feet; and a little farther south at Cedar Creek, on the border of Mohawk Valley, the gravels appear to reach a somewhat lower level.

From Peale diggings to Mohawk Valley the deposits "are similar in being made up of gravel and coarse sand with very little fine sediment," and Turner remarks, "this may be taken as evidence that the river bed had a higher grade than the river beds of the southwesterly system in the western half of the Downieville quadrangle."

Along Haskell Peak escarpment.—South of Mohawk Valley the ancient gravels of Jura River appear in patches at an altitude of about 7,000 feet on the edge of a plateau-like ridge running northwest of Haskell Peak. Here the gravels are overlain by rhyolite, which is in turn locally overlain by andesite. The gravels contain a great variety of pebbles. Turner mentions "contact metamorphic schist, granite porphyry, altered glassy andesite (?) showing flow structure, an altered holocrystalline basalt, a variegated breccia (red and green) made up of microlitic fragments of lava, and a red fine-grained tuff." The last two are very similar to some of the tuffs of the Milton formation and he suggests that they probably came from Chips Hill, farther south, where the Milton formation lies directly beneath the gravel.

Chips diggings, reversed drainage.—At Chips Hill, 3 miles northeast of Sierra City, where the gravel has been extensively mined, it is overlain by rhyolite, and this in turn is covered by andesitic breccia. The bed rock is at an elevation of 6,500 feet, or about 500 feet lower than the gravel of Haskell Peak, with which Turner thinks it was once connected by a stream flowing north. He considers that a great displacement has taken place between Mohawk Valley and Haskell Peak, with differential change of level on the western side of the fault that reversed the drainage from north to south.

Three miles southeast of Sierra City, at an elevation of 6,500 feet, is a trace of river gravel on the edge of a flow of rhyolite that has come down from the crest southeast of English Mountain, which Turner regards as the head of the ancient gravel stream that flowed north by Mount Jura.

Question as to head of Jura River.—The course of the stream beyond Haskell Peak is a matter of doubt. As given above it enters the

Downieville quadrangle near Milton, coming from the Colfax quadrangle, where Lindgren has studied the ancient streams in detail. He refers to a strongly marked depression beginning in the vicinity of Fordyce dam and extending northwesterly in the direction of the Milton-Meadow Lake channel, which he describes, and he concludes from the bed-rock elevations that it turned westward in the vicinity of Milton, where it was joined by "a tributary coming down from the vicinity of Haskell Peak," and remarks,[a] "the high bed-rock ridges near Haskell Peak, the northern side of which has been examined by Mr. H. W. Turner, preclude, except by assuming very large subsequent disturbances, any supposition that the channel could have flowed northward from Milton." It is evident that the difficulty in the way of accepting Turner's view as to the source of Jura River would be removed if it could be made to appear probable that the Milton region, including Chips Hill, had subsided with reference to Haskell Peak and reversed the slope. The argument in favor of this view to be drawn from the relation of the present divide to the main ridge will be considered presently. Attention will be given first to the light thrown on the question by the distribution of the gravels.

The large deposits of gravel at Haskell Peak give positive evidence of a good-sized stream. The gravel, composed, as Turner has shown, of a great variety of rocks, rests directly on granodiorite and must have been brought from some distance. At that time Haskell Peak did not exist. It is made of lavas all of which are younger than the auriferous gravels and overlie them, so that Haskell Peak can not be considered the source of the ancient gravel stream. Whatever the direction of flow of the gravel stream at Haskell Peak, except directly on the line of the crest, it must since have experienced a reversal of drainage slope on the approaching side. The definite knowledge of Jura River and its deposits from Mohawk Valley north demonstrates that it is not the north-slope drainage of Mount Haskell that has been reversed, and points to the south slope as the one reversed.

For 2 miles northwest of Haskell Peak the ancient gravel stream bed follows the divide to a point where the crest is offset to the west. Here the gravel ends. Leaving the divide and following the stream course northwest no gravel is seen for nearly 10 miles, until it appears on Cedar Creek beyond Mohawk Valley. From that point to Mount Jura divide the channel is easily traced.

If now we return to Haskell Peak and try to follow the stream course along the crest to the southeast no trace of it appears, although the crest is bare and well fitted with local lava capping which might reasonably be expected to preserve the gravel in place. It appears most probable, from the absence of gravel on the divide, that the channel lay farther west, more nearly in the direction of the general course of the stream. The known gravel masses which lie beyond Haskell Peak most nearly in the general course of the ancient stream are those of Chips Hill in line with that on the divide north of Milton, suggesting their source for the Haskell Peak gravels.

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[a] Two Neocene rivers of California: Bull. Geol. Soc. America, vol. 4, 1893, p. 276.

Drainage suggested by rhyolite flow.—There is a suggestion of continuous drainage from Meadow Lake to Haskell Peak in the distribution of the rhyolite flows which followed the watercourses, but the suggestion may be misleading, for the rhyolite appears to have come from several sources. The flow from near Meadow Lake, outlined by Lindgren, may have continued as far northwest as Chips Hill, but the large mass farther north, as pointed out by Turner, probably originated in Haskell Peak.

If the drainage at the time of the rhyolite eruption was westward in the vicinity of Milton, and the supply of lava sufficiently large, a westward turn of the rhyolite stream would be expected. Such a turn is suggested in Findley Peak, and others may have been washed away. It is possible, too, that the rhyolite north of Middle Fork of the Yuba came from Haskell Peak. Whatever may have been the course of drainage during the gravel period or at the time of the effusion of the rhyolite, there can be no question that the streams of andesite from the eastward followed essentially the present system of drainage through a gap in the line of the main crest represented by Sierra Buttes.

Suggestion of double crest.—It is important to note that the topography of the region is exceptional in that there are two crests. The main crest between Mount Elwell and Castle Peak passes through Sierra Buttes, Findley Peak, and English Mountain to Meadow Lake, but this crest is not the present divide. The divide curves eastward through Haskell Peak and Webber Peak to near Meadow Lake, as if following the summit of what may be a small fault block east of the main crest between Sierra Buttes and Sierra Valley.

Fan-shaped drainage of the Milton region.—The drainage of the area in question is peculiar in that it is open fan-shaped. Both North Fork and Middle Fork of Yuba River head in this region. Their head branches converge toward Milton, where the two master streams turn west and within 3 miles of each other cut across the line of the old crest south of Sierra Buttes and then diverge down the western slope of the range. The peculiar constriction of these stream courses near their head can not be due to the relatively hard rocks of Sierra Buttes, for such rocks do not appear on the Middle Fork.

Present divide.—The highest points of the Haskell Peak divide are chiefly of volcanic rocks, which are later than the gravels, while the main ridge about Sierra Buttes is made entirely of bed-rock series. It is possible that during the gravel period the main ridge was the divide giving birth to the drainage as outlined by Turner, but at the close of the gravel period, when the Mohawk Valley and Sierra Valley region sank 2,000 feet, the Milton region may also have gone down 500 feet and established a new divide through Haskell Peak.

MAIN MASS OF AURIFEROUS GRAVEL.

The main mass of auriferous gravel is spread in irregular patches over an area about 20 miles in length and 9 miles in breadth, with the greatest dimension parallel to the crest of the Sierra Nevada, on which it lies. Its western portion, in the Moonlight region, will be considered first and then, in order, the northern, eastern, and southern portions.

The Moonlight region.—Moonlight lies 12 miles north of Taylorsville, at the head of Surprise Creek. The divide east of Moonlight, ranging in altitude from 5,600 to 7,000 feet, is drained by the west fork of Lights Creek and affords the most extensive section of auriferous gravels in the region. The total thickness is over 1,000 feet. The lower 400 feet is chiefly sand and the upper 600 feet gravel or conglomerate, which is especially remarkable on account of its lithification.

The conglomerate is sometimes so firmly cemented that when the rock is broken the fracture passes through instead of around the pebbles. This feature gives to the conglomerate an aspect of greater age than the loose gravel possesses. Some of the conglomerate is fine, with pebbles of quartz of various colors and many pebbles of old andesitic rocks, like those of the county-line ridge, to the north. The paste is greenish and, as the microscope shows, is composed largely of igneous material. The smooth round pebbles of the coarse conglomerate are occasionally faulted. Many pebbles are a foot in diameter, and rarely they are 2½ feet, but they average about an inch. A few beds of sand occur in the conglomerate, and when fine they generally contain fossil leaves, of which collections were made. The conglomerate and interbedded sandstone apparently strike N. 10° E. and dip 20° NW. The steep slope east of Moonlight is so covered with faulted landslide blocks that it is difficult to find the rock in place, but the whole succession of conglomeratic beds appears conformable and not less than 600 feet in thickness.

The sandstone beneath the gravel for 100 feet is fairly well cemented and some of it is light gray, like tuff, but the microscope shows it to be made up of angular particles of quartz and some plagioclase with much argillaceous matter and no definite volcanic fragments. Below this the material is softer and landslides abundant. Exposures are few, and the sand of the lower portion of the deposit is arkose. The rocks, too, beneath the sand are largely disintegrated. Traces of leaves occur at many places, and the upper part where firmly cemented makes a rough ridge with steep cliff face to the east. The thick mass of the Moonlight region extends north across the divide to the head of Willards Creek, where it expands into a much larger area, to be noted presently.

South end of Mountain Meadows.—At the southeast head of Mountain Meadows is a body of well-rounded gravel which covers the broad and low divide between Mountain Meadows and Cooks Canyon. The gravel is not cemented, lies flat as deposited, and looks younger than that of the conglomerate east of Moonlight. It represents the unmodified bed of the western branch of the ancient Jura River. The gravel is not very coarse and bowlders are not common. Where mined, it is underlain by sand, and the whole mass is not over 20 feet in thickness. In one mine only 5 feet of gravel was exposed overlying 2½ feet of gray and reddish sand. Upon both sides it is limited by ancient igneous rocks. To the southeast it has been washed away, and thus its connection with Moonlight has been severed. To the northwest it passes beneath the alluvium of Mountain Meadows and does not reappear until the northern end of the meadows is reached at the Narrows. The slope east of Mountain Meadows is generally free from gravel and is formed of ancient volcanics capped here and there by later flows of lava which have not been mapped.

North end of Mountain Meadows.—The Red Bluff-Susanville road is on gravel from the north end of Mountain Meadows across the divide to near Stocktons, a distance of about 10 miles. West of the summit the streams (dry in summer) which enter the meadows from the southeast at Nanney and Browns afford sections of about 500 feet of gravel capped on the crest by lava and tuff. The gravel has a large proportion of siliceous pebbles. Many are of black chert, with others of old sandstone and conglomerate and a few of older igneous rocks. In this regard as well as in their general lack of cementation they are strongly contrasted with the deposits of older gravel on the slope east of Moonlight. These gravels south of Browns, so clearly capped by lava and tuff, are underlain by sand, which gives rise to many landslides, some of whose basins still contain swamps or ponds. This pitted surface has the aspect of a moraine, but contains no bowlders, and passes into protected portions which are not only free from landslides, but pass beneath the capping layer of andesite tuff. Half a mile southeast of Nanney was found a smooth round pebble of fossiliferous sandstone like that of Hinchman Ravine on Mount Jura. Near the summit of the gravel pebbles of modern lava become abundant, but no definite horizon was observed at which the pebbles of modern lavas begin to appear.

Generally the gravel about Mountain Meadows is not cemented, but a rather striking exception to the rule occurs one-fourth mile northwest of Browns, where the cemented sand and gravel rich in quartz forms a low divide and is overlain by loose gravel, which is finally capped to the northwest by volcanics. It seems probable that the cementation of the gravel in this case may be due to the intrusion of the andesite which forms the bluff opposite Nanney.

Willards Creek district.—On the slopes of Willards Creek the auriferous gravels are exposed to a thickness of over 500 feet, but the sediments are not so firmly cemented as those east of Moonlight and at the head of Gold Run. The gravels exposed contain numerous pebbles of fresh lava with those of black chert, sandstone, and other siliceous material, which appear to have been derived from earlier gravels by erosion. One of the pebbles of gray sandstone contained a characteristic *Rhynchonella* of the Mormon formation of Mount Jura near Taylorsville, and indicates clearly its source. The following section was observed 1½ miles southeast of the road summit:

Section near road summit, Willards Creek district.

	Feet.
Andesitic volcanic breccia	20
Gravel containing many lava pebbles with older ones of chert, etc	75
Sandstone with a little fine conglomerate and light-colored beds of fine rhyolitic tuff	90

No satisfactory exposure was obtained of the material underlying the rhyolitic tuff.

The tuff is composed largely of light-brown amorphous dust, splinters of clear glass with fragments of clear glass pumice, and angular grains of quartz, feldspar, augite, and hornblende. It is decidedly cross-bedded and appears to dip gently to the northeast.

A chemical analysis of this rhyolitic tuff (p. 92) shows that it is apparently identical with the rhyolitic tuff which caps the earlier gravels at various places on the western slope of the Sierra Nevada. Unfortunately, on Willards Creek the part of the section below the rhyolitic tuff was not found exposed.

Head of Gold Run.—Gravel occurs along the Taylorsville road most of the way down Gold Run. Near its head west of the road where firmly cemented the conglomerate has a thickness of over 350 feet, dips gently to the northeast, and forms prominent cliffs. At this point the conglomerate varies in the size of the pebbles, but is rarely coarse. Some of the pebbles are crushed and faulted in a way to indicate great strain. These effects were observed only in the conglomerate near the crest of the range, from which considerable material may have been removed by erosion. Many of the pebbles are of old volcanic rocks like those noted in the gravels east of Moonlight. The interbedded lenses of fine sediment occasionally contain fossil leaves, of which an excellent series of specimens were collected by James Storrs in 1904. They were obtained about three-fourths of a mile northwest of the road summit and 350 feet below it, on a branch of the west fork of Gold Run. Dikelike bodies of hornblende andesite cut the conglomerate gravels at this point, and their intrusion may have had something to do with the induration of the gravel mass.

Diamond Mountain gravel.—On the Sierra crest, a few miles southeast of the Lights Canyon road summit, there are two high points, both composed of andesitic breccia. The west one is commonly known as Red Mountain on account of the colored tuff, while the other, about a mile to the northeast, is called Diamond Mountain. Between them is a ridge of gravel which is overlain by the volcanic breccias of the two peaks. Near Red Mountain the gravel of this ridge is composed largely of quartz, chert, and old sedimentary as well as igneous rocks. Farther east as the ridge rises lava pebbles come in, and near the top the pebbles are almost wholly of lava. The contrast between the earlier quartzose gravel and the later directly overlying gravel of lava fragments is striking. The gravel contains occasional bowlders, some of which are 12 feet in diameter and entirely out of accord with the associated well-rounded gravel. One bowlder and several large pebbles were found with striæ, but no definite glacial moraines were distinguished.

Southeast of Diamond Mountain a prominent ridge of gravel forms the crest of the Sierra for several miles at an altitude of over 7,000 feet, overlooking the bold escarpment facing Honey Lake Valley. The gravel of this prominent crest ridge is about 300 feet in thickness and rests on the granite which outcrops on the eastern slope. The gravel is coarse and chiefly of andesitic fragments on the surface, but near the bottom is finer, though the lower half of the mass contains most of the granite bowlders strewn on the eastern slopes. The ridge is separated from Diamond Mountain by a gap from which the gravel has been removed. A small pond occurs in the gap, and a flow of basalt with flow structure rising to the northeast forms a cliff facing in the same way as if the lava flow came from that direction. Similar basalt hangs on the granite slope a mile to the southeast. A small gravel scarp near the pond suggests faulting.

Gravel has been mined to a very limited extent along the eastern base of the Sierra, a short distance south of Gold Run, 4 miles from Susanville, but no large body of gravel is exposed at that point. If it ever extended so far east, it has probably been covered by the later lavas and lake deposits of that region.

Diamond Mountain shore terraces.—Shore terraces are well developed about Diamond Mountain, as though it were an insular mass against which the waves beat and carved out a shore line. As shown in fig. 9, Diamond Mountain has five spurs running in various directions. The summit of the mountain is (1) andesitic breccia, about 300 feet in thickness. On each spur the breccia is limited by a more or less clearly defined shore cliff, beyond which is a mass of (2) gravel composed almost wholly of well-rounded lava fragments.

Beyond the lava gravel (2) on most of the spurs at a lower level comes (3) the gravel in which pebbles of Tertiary lavas are rare or absent and pebbles of quartzose rocks are most abundant. Their general relations in a vertical section are shown in fig. 10, where the numbers have the same significance. The total thickness of the gravel is less than 300 feet. Granite bowlders appear to be most abundant on the lower half of the gravel. Farther southeast along the crest under the thick mass of basalt flows, forming Thompson Peak, there is no gravel separating it from the granitic rock. On the contact the basalt includes a residual bowlder of diorite, showing that the basalt flowed over a surface long exposed to disintegration.

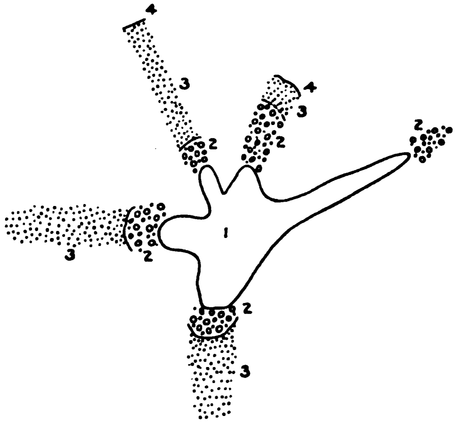

FIG. 9.—Sketch plan of Diamond Mountain, showing shore terraces on spurs. 1, Andesitic breccia forming summit; 2, gravel of lava pebbles on shore terraces on spurs; 3, gravel rich in quartz pebbles; 4, granodiorite.

Lone Rock and Kettle Rock regions.—Southwest of Diamond Mountain, in the flat country drained by the headwaters of Indian Creek, the gravels are widely distributed in a heavy body, although much of it has been removed by erosion. The east border laps over upon the granite without any lava capping and extends south, sending a branch to the forks of Indian Creek, where it ends at an elevation of about 1,000 feet below the main crest of the gravel ridge. West of Lone Rock, on the branches of the south fork of Lights Creek, the gravel was not cemented and has been largely removed, leaving on the lower slopes but a thin coating on the arkose sands, which contain occasional well-rounded quartz pebbles to show that they are not residual but recomposed. Farther south it caps the broad divide rising toward Kettle Rock, and above the Lucky S mine reaches

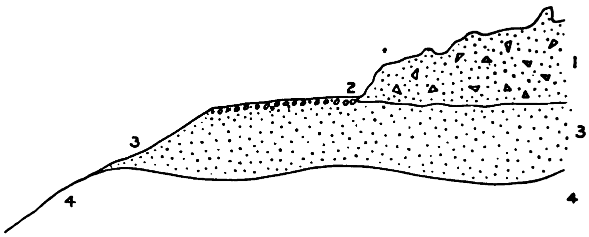

FIG. 10.—Generalized section of spur of Diamond Mountain. 1, Andesitic breccia; 2, gravel of lava pebbles; 3, gravels rich in quartz pebbles and sand below; 4, granodiorite.

an altitude of over 7,000 feet. Several hundred feet of gravel occur here. The lower part is fine, with many pebbles of quartz and siliceous rocks, and the upper part, associated with the volcanic breccia, is composed chiefly of andesitic fragments. The earlier gravels near the Lucky S mine were once connected with those of a few miles southward on the Mount Jura divide, but the later gravels of lava pebbles present above the Lucky S mine appear to be absent on the Mount Jura divide.

ISOLATED MASSES OF GRAVELS NORTHEAST OF MOHAWK VALLEY.

This country forms the eastern slope of Jura River and is somewhat remarkable for the paucity of its gravels. The principal body found in this region is near Mapes, on Squaw Creek, 5 miles northeast of Chase's, where a knoll on the meadow border is made up of cobblestones and pebbles of granite and dark shaly rock, with many of lava. Though of small extent it is a veritable washed gravel, and must once have underlain an adjacent mass of lava several hundred feet in thickness. Whether the gravel rests directly on the granodiorite or is separated from it by a thin sheet of volcanic rocks was not definitely determined.

Traces of gravel and bowlders were found on the west side of the crest opposite Milford, but similar pebbles occur in the associated tuff, and they may have been liberated by weathering. By a small area of altered rocks inclosed in the granodiorite, 3 miles southwest of Clark's dairy, there is a small mass of quartz gravel locally developed, which may represent a small stream extending to the margin of the delta gravel only a few miles to the northwest.

A few pebbles of quartzose rocks were found near Chase's on Red Clover Creek, but no definite body of gravel was seen in place. However, it is not only possible but probable that a stream passed near there, for on the north slope of Mount Ingalls is a mass of well-rounded coarse gravel of lava fragments deposited during the volcanic period, but most likely representing a descendant of a stream of the prevolcanic period.

The contact of the gently rolling platform of granodiorite and the overlying sheet of volcanic rocks was examined at many points about the heads of Squaw and Last Chance creeks without finding a trace of gravel, and it is certain that the great sheet of estuarine gravel, which at Diamond Mountain lies between the sheet of volcanic rocks and the granodiorite, does not extend south of the latitude of Kettle Rock.

Along the fortieth parallel east of Red Clover Creek granodiorite forms a broad platform gently inclined to the northwest. It is covered throughout most of the area by a sheet of volcanic rocks whose thickness is only a few hundred feet. The thin cover it makes for the granodiorite is especially well exposed along the eastern escarpment, where it appears only on the crest. The escarpment is of granodiorite.

CLASSIFICATION OF THE AURIFEROUS GRAVELS.

The early investigations of the Geological Survey of California under J. D. Whitney proved the fluviatile origin of the gravels, but it remained for the later workers, especially Ross E. Browne, H. W. Turner, and Waldemar Lindgren, to work out their classification. The latest expression on the subject is by Lindgren,[a] who states that in the principal broad Neocene river valleys one may generally distinguish the following formations:

A. Antevolcanic deposits	1. The deep gravels. 2. The bench gravels.
B. Volcanic and intervolcanic deposits.	3. The rhyolitic tuffs. 4. The gravels of the rhyolitic period. 5. The gravels of the intervolcanic erosion period. 6. The andesitic tuffs and tuffaceous breccias.

For various reasons the gravel deposits where thickest, east of Moonlight and at the head of Willards Creek, are not worked, so that complete and detailed sections are nowhere available. The lower portion of the mass especially is affected by landslides, and outcrops are few. As a whole the deposits of the Taylorsville region included under the general term auriferous gravels may be considered under the following headings:

EARLIER DEPOSITS (PREVOLCANIC).

Arkose sands.—At every point where the bottom portion of the main mass is exposed it is found to be composed of sand, and the greater part, especially the lower, is often decidedly arkose, so much so that in some of the mines it was difficult to tell whether the material was simply disintegrated granodiorite in place or recomposed. In most cases careful search ultimately brought to light a few small but smooth round quartz pebbles to prove it arkose. Gravel beds in this portion are rare. In some cases carbonaceous clay beds, amounting even to impure coal, occur, but it is not certain that they underlie the main mass, though the sand is believed to underlie the whole with a variable thickness, and a local maximum of not less than 500 feet. Some of it is lithified, forming sandstone.

When we turn to the river channel some distance above where it joins the main deposits, as, for example, at Peale diggings and farther up the stream, the fine beds at the bottom have disappeared. It is to be expected, of course, that the main mass in general is older than that in the channel, which is ever moving downstream to join the delta.

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[a] Jour. Geology, vol. 4, 1896, p. 881.

The prevolcanic gravels.—These gravels usually contain more or less pebbles of white quartz with others prevailingly quartzose, and all are derived from the bed-rock series, among which there are many igneous rocks, but no Tertiary lavas. The material ranges in size from occasional sand streaks to scattered bowlders up to 12 feet through, but the greater number of the pebbles are from 1 to 4 inches in diameter. Locally they are cemented so as to form conglomerate. The gravels of the Jura River bed throughout its whole course, as well as the bulk of the gravels of the delta, belong to this horizon. It has a maximum thickness of over 500 feet, and near its base contains fossil leaves.

It has not been found possible at any point I have had an opportunity to examine along the course of Jura River to distinguish the deep gravels and the bench gravels described by Lindgren. The great bulk of the stream gravels in the broad channel are undoubtedly bench gravels, but the presence of the deep gravels could not be clearly demonstrated. More extensive mining may bring them to light. However this may be, the equivalents of both deep gravels and bench gravels most likely occur in the main mass, but have not yet been distinguished.

LATER DEPOSITS (INTERVOLCANIC).

Rhyolitic tuff.—In the region of Willards Creek rhyolitic tuff was found interbedded with sandstone between masses of conglomerate, and it belongs in the succession of gravels before the eruption of the volcanic breccia. There are several beds of tuff grading into sandstone which are very similar to the rhyolitic tuffs which Lindgren and Turner have described as overlying the bench gravels in the Sierra Nevada south of the Taylorsville region. Rhyolite flows occur at Haskell Peak and beyond, overlying the gravels to the head of Jura River, and are themselves overlain by flows of andesite breccia, but both kinds of flows are generally absent from the ancient river channel north of the fortieth parallel until the main mass is reached in the vicinity of the present crest. Chemical analyses of the rhyolite tuffs farther south are not available for comparison, but Lindgren, who has kindly examined the slides and specimens from Willards Creek, recognizes them as being practically identical with the rhyolite tuff to which he refers.

Intervolcanic gravels.—Overlying the rhyolitic tuff and sandstone on Willards Creek is a mass of gravel containing a considerable proportion of lava pebbles, and these increase in amount upward through a thickness of about 75 feet. These were found at only one place, and were not studied in great detail at the time, but they appear to lie conformably between the andesitic breccia and rhyolitic tuff and find their equivalents most likely in those of the rhyolitic period and intervolcanic-erosion period of Lindgren.

Volcanic flows, chiefly andesitic breccia.—This material is mainly of hornblende and hypersthene andesite, often in the form of breccia, such as filled the broad valleys and covered the rhyolite flows and auriferous gravels at many points. Their source in the Taylorsville region is fairly well marked at Red Mountain, near Diamond Mountain, and a few miles farther northwest on the crest, and by their extrusion over the submerged end of the Sierra Nevada the bottom became very irregular. As eruptions progressed the water became more shallow, with islands along the summit.

Shore gravel.—The islands along the crest are bordered by beach platforms paved with coarse gravel and cobblestones of andesite, with a few of basalt derived directly from the adjacent shore. Their lower portions locally join the intervolcanic gravels, but their relations could not be fully determined. The prevolcanic gravels at Moonlight and the head of Willards Creek, as already pointed out, have a decided dip of from 15° to 20°, which appears to indicate tilting after deposition; but as clearly bedded andesitic tuff associated with the volcanic breccia shows the same inclination, it appears that the tilting took place in the final movement after all the gravels were deposited, possibly with essential conformability throughout.

IONE FORMATION.

The Ione formation, made up chiefly of sand and gravels, lies along the western base of the Sierra Nevada in the Sacramento Valley, where Lindgren[a] has found that it contains Miocene shells, and with Turner[b] has shown that it was deposited synchronously with the older auriferous gravels. The Ione formation is extensively developed in the eastern part of Shasta County, from Cow Creek to Kosk Creek, beyond the great bend of Pit River, and contains fossil leaves and local traces of coal. The strata dip easterly beneath the great mass of Tertiary lavas about Lassen Peak, and are believed to represent the same geologic horizon, and possibly are connected with the great mass of auriferous gravels which disappear beneath the same lavas at the north end of Mountain Meadows. This correlation is practically demonstrated by a comparison of their floras.

FLORA OF THE PREVOLCANIC GRAVELS.

The only fossils found were in the earlier auriferous gravels, and collections were made at two localities—one near the eastern end of Moonlight on the slope toward the west fork of Lights Creek, at an elevation of about 6,000 feet, the other three-fourths of a mile north of the road summit between Taylorsville and Susanville, at an elevation of 6,000 feet on the slope of Gold Run, and about 7½ miles southwest of Susanville. Fossils were collected years ago from the same mass of gravel[a] at the head of Mountain Meadows and also three-fourths of a mile north of the Lights Canyon road summit. Plants from both these localities have been tabulated with the later collections for comparison with those from the auriferous gravels of the Sierra Nevada south of the Taylorsville region, as well as those of the Ione formation on Little Cow Creek and Kosk Creek of Shasta County. The earlier collections examined by Professor Lesquereux have been studied by Knowlton, whose determinations are given in the following table, which contains all the forms thus far identified in the Taylorsville region and in the Ione of Shasta County:

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[a] Jour. Geology, vol. 4, 1896, p. 890.

[b] Am. Geologist, vol. 15, 1895, p. 373.

Tertiary fossils from Taylorsville region and vicinity.

Name.	Kosk Creek, head, Shasta County.	Kosk Creek, Shasta County.	Little Cow Creek, Shasta County.	North Mountain Meadows, Plumas County.	Moonlight.	7¾ miles southwest of Susanville, Lassen County.	Sierra Nevada south of Taylorsville region.
Acer Bendirei Lesq							6
Alnus Kefersteinii Al. Br			+				
Aralia lasseniana Lesq						+	
Aralia Whitneyi Lesq						+	2
Asplenium Wegmanni						+	
Cinnamomum Scheuchzeri or polymorphum, Al. Br				+			
Fagus Antipofii Abich		+					3
Ficus asiminæfolia Lesq			+				5
Ficus microphylla Lesq			+				
Ficus tiliæfolia Al. Br		+					2
Ficus shastensis Lesq			+				4
Juglans Bilinica Ung			+				
Juglans egregia Lesq	+						1 and 2
Juglans rugosa Lesq						+	
Laurus californica Lesq			+		+	+	2 and 6
Laurus salicifolia Lesq						+	6
Laurus grandis Lesq						+	
Leguminosites sp						+	
Magnolia californica Lesq		+					1 and 2
Magnolia Hilgardiana Lesq						+	
Magnolia Inglefieldi Heer						+	
Magnolia lanceolata Lesq						+	2
Myrica Ungeri Heer							6
Oreodaphne litsæformis Lesq						+	
Persea Dilleri Lesq			+			+	4
Persea pseudocarolinensis Lesq		+				+	1 and 2
Phragmites œningensis Al. Br				+		+	
Platanus appendiculata Lesq					+		2 and 4
Platanus dissecta Lesq			+				2 and 6
Populus Zaddachi Heer		+	+		+	+	1, 2, and 4
Pterospermites spectabilis Heer							6
Quercus convexa Lesq		+			+		2 and 3
Quercus distincta Lesq	+						1 and 2
Quercus gigantissimus Kn						+	
Quercus Moorii Lesq						+	
Quercus Olafseni Heer						+	
Quercus Boweniana Lesq					+		2
Quercus n. sp. cf. Q. elænoides					+		2
Rhus metopioides Lesq					+		
Rhus mixta Lesq		+					2
Sabalites californicus Lesq		+					2
Salix californica Lesq					+		2
Sphenopteris Guyottii Lesq	+						
Ulmus californica Lesq		+					1 and 2
Ulmus pseudofulva Lesq					+		2

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[a] Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 420.

In the final column of the table the particular locality at which the species has been found is indicated by figures. 1 = Chalk Bluff, 2 = Independence Hill, 3 = Table Mountain, 4 = Volcanic Hill, 5 = Rock Corral, and 6 = Monte Cristo mine, Spanish Peak. The fossils from Little Cow Creek and Kosk Creek, Ione formation, are from essentially the same mass. The same is true also of the three localities of the Taylorsville region. For purposes of comparison, therefore, the localities noted in the table may be grouped under three heads; Ione of Shasta County, northern end of the Sierra Nevada, and western slope of the Sierra Nevada.

In the Ione of Shasta County 20 species have been identified, and of these 18 have been recognized in the earlier gravels of the western slope of the Sierra Nevada, leaving no room for doubt that the two formations are for the most part synchronous in origin.

Twenty-seven species have been identified in the gravels of the Taylorsville region, of which 13 occur in the gravels of the western slope of the range, a correspondence which is sufficiently marked to show that the gravels of the two regions are closely related in age.

AGE OF THE PREVOLCANIC AURIFEROUS GRAVELS.

GENERAL STATEMENT.

The age of the auriferous gravels of the Sierra Nevada in California is generally given as late Miocene or Pliocene and is based chiefly on fossil plants and a few animal forms.

In his report on the later collections of fossil plants from the gravels of the Taylorsville region and the earlier collections from the Ione of Shasta County, Knowlton says that they are typical of the auriferous gravels and nothing in the collection suggests an age as old as the Eocene. This statement does not apply to the earlier collections determined by Lesquereux, which Knowlton regards as of greater age.

The auriferous-gravel period in all probability was a long one, and no considerable part of its flora has yet been connected directly with its contemporaneous marine fauna of the same region. On physiographic and stratigraphic grounds and the general relations of the Sierra Nevada to sedimentation, it has long been supposed by some geologists that the oldest auriferous gravels, the deep gravels of Lindgren, are probably Eocene, but the evidence assigned is problematical rather than positive.

The locality 7½ miles southwest of Susanville, as given in the foregoing table, is essentially the same as the one[a] three-quarters of a mile north of where Light Canyon and the Susanville road cross the summit. The small lens of shale from which the plants were collected in 1886 was exhausted, but another shaly lens near by in the same conglomerate furnished the material collected by James Storrs in 1904. The lenses differ lithologically and the floras are different, but they are reported by Storrs to be in the same mass of conglomerate and therefore of essentially the same age. The earlier collection was regarded by Lesquereux as Eocene.[a]

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[a] Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 420.

EOCENE FLORA OF SOUTHWEST OREGON.

While studying the Eocene deposits of the Roseburg, Coos Bay, and Riddles quadrangles in Oregon fossil leaves were found in the same strata with marine shells, affording an opportunity to definitely connect the land flora with its contemporaneous marine fauna.

The following list of 10 species embraces the Eocene plants identified by F. H. Knowlton with more or less certainty from a number of localities within the area noted above:

Magnolia lanceolata Lesq.
Magnolia californica? Lesq.
Laurus californica? Lesq.
Sabalites californicus? Lesq.
Aralia Whitneyi Lesq.
Populus Zaddachi Heer.
Aralia angustiloba? Lesq.
Juglans californica? Lesq.
Ulmus californica Lesq.
Ficus tiliæfolia? Al. Braun.

Among the shells found with or near the fossil leaves Dr. W. H. Dall has recognized over 20 genera, and remarks: "The fossils are Eocene. They contain a number of interesting things, particularly the Orbitolites, which is usually characteristic of the Oligocene on the Atlantic coast and is now for the first time recognized from the Pacific coast."

The fossil leaves were found near the southeast border of the Eocene, where shells are not abundant, but a short distance farther northeast they become very abundant locally with such characteristic forms as *Venericardia planicosta* and *Turritella uvasana*, and there is no doubt concerning the Eocene age of the strata containing the fossil leaves.

Of the 10 species of plants identified 7 are somewhat in doubt, but 3, *Magnolia lanceolata*, *Aralia Whitneyi*, and *Populus Zaddachi*, are completely satisfactory. They all occur in the auriferous gravels of Independence Hill, on the western slope of the Sierra Nevada, as well as on the summit of the northern end of the range, 7½ miles southwest of Susanville. The last species occurs at many other localities, among which may be mentioned the Ione formation of Kosk Creek and Little Cow Creek of Shasta County and the auriferous gravels of Moonlight, Chalk Bluff, and Volcanic Hill.

Eight of the 10 species reported from the Eocene of Oregon occur, according to Lindgren, in the bench gravels of Independence Hill, in California. It seems probable, therefore, that not only the "deep gravels," but also the "bench gravels," both of which belong to the prevolcanic gravels, may be of Eocene age.[b]

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[a] Proc. U. S. Nat. Mus., 1888, vol. 11, p. 28.

[b] Proc. Washington Acad. Sci., vol. 8, 1907, pp. 405-406.

TOPOGRAPHY OF THE AURIFEROUS-GRAVEL PERIOD.

The two divides.—The drainage of the Taylorsville region during the auriferous-gravel period clearly supports the view that the Sierra Nevada was then a conspicuous range of mountains with two divides at the north end separated by a longitudinal valley draining to the north. The first or main crest represents the continuation of the great divide of the range northwest from Castle Peak by Sierra Buttes and Mount Elwell to Spanish Peak, and the second, as shown by Lindgren, lies farther east and extends north toward Honey Lake, forming, at least in part, the east front of the range. These two summit crests in a general way outlined the drainage basin of Jura River, which flowed north between them to the estuarine body of water that probably covered a large part of the Lassen Peak region and connected directly with an arm of the sea in the Sacramento Valley. The estuarine-covered portion of the Taylorsville region was apparently about sea level during the gravel period.

Altitude of the region.—The flora of the Taylorsville region during the gravel period is in strong contrast with that of the same region to-day, and supports the view drawn from the drainage that the northern end of the range during the deposition of the prevolcanic gravels was much lower than now. This statement is not intended to apply to the range south of the fortieth parallel for the streams headed in that direction, and it is evident that the range there had greater altitude. In that direction Lindgren has shown by a careful study of stream grades that since the gravel period the summit of the Sierra has been raised with reference to the Sacramento Valley so as to increase the slope to the southwest.

Jura River Valley.—Jura River headed in the main divide and flowed parallel to its base for many miles before turning more nearly north. West of the river the valley had a short, steep slope from the main crest, while on the east there was a long, gentle slope to a distant crest. The paucity of gravels on the slope east of the river may be taken as an indication of the smallness of the streams as compared with the main river with its well-marked gravel course.

Small masses of gravel containing pebbles of lava were found on Squaw Creek (Pl. II), near Mapes, 4 miles northeast of Chases, and traces occur also in Red Clover Valley, with a larger mass, of lava pebbles only, south of Genesee Valley, but no definite evidence has yet been reported east of the bed of Jura River to indicate the former presence in that region of an important contemporaneous stream.

Drainage of Sierra Valley.—No definite connection has yet been traced between Jura River and Sierra Valley, whose records of the auriferous-gravel period are concealed beneath a cover of volcanic rocks and lake beds. Lindgren has traced the sunken area or moat, as he appropriately calls it, of the Lake Tahoe region as far north as

Sierra Valley and suggests[a] that during the gravel period the drainage may have been north. So large an area would give rise to a large stream and important deposits would be expected to record its course. A suggestion of its existence may probably be found in the observation of Turner,[b] who reports bowlders and pebbles of rhyolite in the auriferous gravels near Cedar Creek, at the north end of Mohawk Valley lake beds, and remarks "that a portion of this gravel is of later age than that of the Haskell Peak channel, which is capped with rhyolite."

Uplift in gravel period.—The lower portion of the gravel deposits of the main area in the Taylorsville region is sand and the upper portion gravel, often coarse and containing bowlders. This decided and general change in the character of the sediment delivered by Jura River must have resulted from an increase of grade within the prevolcanic-gravel period, a change which under the circumstances points for its origin to a rise in the main crest of the range about Haskell Peak or farther south.

QUATERNARY.

Gravels of Keddie Ridge.—Three miles directly east of Greenville, on the west slope of Keddie Ridge, at an altitude of 4,100 feet, is a considerable body of well-rounded gravel forming the flattish summit of a spur. The pebbles are chiefly of quartzite, gray, black, and rarely red flinty rocks with fragments of slate and granite, and a few are of andesitic lavas. A prospecting shaft has been sunk 20 feet in gravel and sand and shows the pebbles dipping easterly toward a gap in the Keddie Ridge through which the depositing stream may have passed. The deposit is about 50 feet thick, 200 yards wide, and nearly half a mile long in the direction of the general course of the stream.

Gravels near Greenville.—On the valley border 1 mile northeast of Greenville there is a mass of gravel exposed along the road for over half a mile. It is associated with soft whitish material, which may be volcanic, and is overlain by a sheet of andesitic lava in which pyroxene is the characteristic mineral. The two masses of gravel just noted probably belong to the same stream, which seems to have flowed across the gap of Keddie Ridge from the region of the head of North Arm, and may represent an early diversion of Jura River. Whatever may have been its source the topography of its time was very different from that of to-day.

North Arm pothole.—An interesting pothole occurs on the southeast side of North Arm, near Mr. Thompson's, 1½ miles northeast of Taylorsville. The waterworn rock is the Thompson limestone about 100 feet above the level of the adjacent valley border. The pothole is 2½ feet in diameter and 3 feet deep and contains a lot of well-worn gravel at the bottom to testify in a very satisfactory manner to its origin. There is no stream near it now, and the only reasonable explanation apparent ascribes it to the North Arm stream fashioning the slopes of the valley at that level.

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[a] Truckee folio (No. 39), Geologic Atlas U. S., U. S. Geol. Survey, 1897, p. 6.

[b] Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 611.

Shoo Fly gravel terraces.—On the right bank of Indian Creek below Shoo Fly there are terraces ranging from 300 to 600 or more feet above the stream. Most of these terraces have a capping of rhyolite or basalt, and some have traces of gravel, but no large body of gravel was observed anywhere except on the low benches near the present stream level. These gravels are evidently of late origin, were deposited by Indian Creek, and according to Lindgren are distinctly connected with the Pleistocene gravels of American Valley.

Glacial moraines.—Glacial phenomena in the Taylorsville region are very meager and confined to the eastern slope of Grizzly Mountains. The small ravine heading against the northern side of Tower Rock had sufficient gathering ground at an altitude of 7,500 feet to give rise to a glacier over a mile in length. Its morainal deposits are strewn over the slope from 6,000 down to nearly 4,500 feet, where there is a prominent terminal mass. Higher up a lateral embankment is well marked on the west side.

A short distance farther north is a small lake due to a small moraine dam. The Devils Punch Bowl is an excellent example of the same sort. Crystal Lake of Houghs Peak is another example, and probably also Taylor Lake, near Kettle Rock.

Valley alluvium.—Valley alluvium is the sediment which fills the valleys and makes the level surface of Indian Valley, North Arm, and Genesee Valley. It contains some gravel, especially where streams enter the valleys. Sand is more widely distributed, but silt is the most common material and makes an excellent rich soil for agriculture.

The depth of the valleys and the character of the material below is not known. No deep borings or wells have been made. It is apparent, however, from the occurrence of the Mounds, which are simply knolls on a spur from Keddie Ridge, that Indian Valley is deepest on the western side.

IGNEOUS ROCKS.

GENERAL ACCOUNT.

The igneous rocks of the Taylorsville region are the same as those of the Sierra Nevada south of the fortieth parallel, which have been described in detail by Turner, Lindgren, and Ransome in various folios and special papers. This renders an extended treatment of them at this place unnecessary.

The igneous rocks include representatives of both acidic and basic types, some intrusive but most of them effusive, and are scattered at intervals through geologic time from the early Silurian to the Quaternary. The Paleozoic and early Mesozoic igneous rocks of the Taylorsville region are chiefly lavas which have been much altered from their original condition. To indicate the change the altered forms are designated metarhyolite and meta-andesite.

The earliest eruptive recognized in the Taylorsville region is the metarhyolite at the base of the Silurian quartzite. It is a large mass having a probable thickness of over 1,000 feet. This was succeeded in Carboniferous time by extensive eruptions of meta-andesite of great thickness, separable into three subordinate masses, Taylor meta-andesite, Kettle meta-andesite, and Reeve meta-andesite, each of which is outlined on the geologic map.

During Jurassic time volcanoes were again active near Taylorsville and the Fant and Hull meta-andesites were erupted. A great change took place about the close of the Jurassic, and the intrusive rocks of that time are strongly contrasted with the earlier lavas. Instead of metarhyolites and meta-andesites we have holocrystalline granular rocks, such as granodiorite, serpentine, pyroxenite, and various rocks occurring in dikes. The Tertiary volcanics are of three types, rhyolite, andesite, and basalt.

PRE-SILURIAN.

METARHYOLITE (QUARTZ PORPHYRY).

General description.—This is a massive gray siliceous rock which generally contains phenocrysts of quartz or feldspar embedded in a uniformly fine, compact groundmass. In the most common form on the slope of Grizzly Mountains phenocrysts of feldspar are absent, and those of quartz often inconspicuous or absent, but elsewhere both are usually abundant. Flow lines are not generally present but are sometimes conspicuous. Part of the mass is distinctly fragmental, made up of angular pieces of metarhyolite cemented by material of essentially the same sort. On a weathered surface the fragments usually become much lighter than the true interstitial material and make the brecciated character of the rock conspicuous, and it appears to be a veritable flow breccia. In other portions there are occasional bright-red fragments of various shades and tints which give prominence to its structure. Some of the fragments are rounded, suggesting attrition, while others are amygdaloidal, as if originally vesicular, suggesting volcanic ejection, though no positive fine volcanic tuff was discovered.

Much of the metarhyolite has a decided schistose structure, which is in some places approximately parallel to the lines of flowage. On the lower slope of Grizzly Mountains the structure is very well developed and dips to the southwest parallel to the flow lines and the general stratification of the mountains. That this structure is due to compression and consequent shearing is shown by the fact, seen under the microscope, that the grains of quartz are crushed and displaced along the same lines.

Occurrence.—The mass designated as metarhyolite is complex, being made up of surface flows, some of which are thoroughly brecciated, intermingled with much ejected fragmental material spread over the country before the deposition of the Grizzly formation.

Relation to adjacent rocks.—The relation of the metarhyolite to the Grizzly formation is of greatest importance and has already been considered in connection with the quartzite. The pebbles of metarhyolite in the overlying quartzite afford definite and conclusive evidence that the quartzite was deposited upon the metarhyolite. The original surface of the siliceous lava was probably very rough and irregular, and these features have been intensified by deformation. On the lower slope of Grizzly Mountains opposite Huntington the ancient rhyolite has well-marked fluidal structure, in general parallel to the surface on which the quartzite was laid down and subsequently folded.

After determining the relation of the metarhyolite to the Silurian quartzite it is easier to understand its relation to sediments of later age. The Taylorsville formation, like the Grizzly, is folded or faulted into the metarhyolite, but in the case of the Arlington and later formations the sediments overlie the metarhyolite with evidences of less subsequent disturbance.

Distribution.—Metarhyolite is especially wel developed on the eastern slope of Grizzly Mountains. To the southeast it extends as a narrow belt for 11 miles into the Downieville region, where it has been recognized by Turner as made up of volcanic flows. To the north and northwest from Grizzly Mountains its area widens so as to form Keddie Ridge and the hills between Crescent Mills and Greenville and beyond, where it is covered by the later formations. It is possible that the igneous rock of this large area is not all of the same age. A small part of it may belong to the rhyolite erupted at the close of the Jurassic, and occurring as dikes in the earlier form, but the close similarity between the two rocks rendered it impracticable to separate them in all cases.

CARBONIFEROUS.

TAYLOR META-ANDESITE.

General description.—This rock is decidedly green and is generally designated greenstone by the miners. Where not too much altered it is porphyritic with numerous crystals of augite and occasionally feldspar, but in most cases the porphyritic structure has been obscured in the development of an imperfect cleavage.

Much of the rock has a decidedly fragmental structure, which is most plainly visible on a weathered surface. The fragments in some places are clearly vesicular and show that the fragmental material is really tuffaceous and represents explosive volcanic action, but it is rarely if ever a coarse agglomerate. In other cases, however, vesicular fragments are few or absent and the rock passes into a fine conglomerate. The matrix, like that of the tuff and the altered groundmass inclosing the phenocrysts of augite, is composed in large measure of secondary hornblende, chlorite, epidote, and quartz. The Taylor meta-augite andesite generally has an imperfectly developed slaty structure and is often traversed by quartz veins, many of which follow the lines of cleavage. Occasionally the rock is full of quartz amygdules, which stand out on the weathered surfaces, giving the rock the aspect of a quartz porphyry.

The phenocrysts of augite are rarely complete crystals. Some of them show one or more crystallographic boundaries, but for the most part they are fragments of crystals irregular in outline. Many of them have traces of a lighter colored fringe of enlargement.. Phenocrysts of plagioclase are not common and the groundmass is generally so altered as to be completely replaced by epidote, chlorite, hornblende, and quartz, but where preserved it is made up of minute elongated crystals of feldspar arranged in streams. No definite trace of diabasic structure was found.

Occurrence.—Taylor meta-augite andesite occurs in irregular sheets which represent lava flows from ancient volcanic vents intermingled with clastic material blown from the same craters. One of the best localities to observe the relations is about Taylor Rock, where the tuffaceous portion is well exposed. The mass, as already noted, generally has more or less prominent cleavage planes which strike northwest and southeast, parallel to the general strike of the formation, and dip to the southwest. Owing to deformation and alteration the position of the lava flows and tuffs is difficult to determine, but generally they lie in sheets approximately parallel to the stratification of the sediments between which they outcrop. That this is their true position can be best determined in the canyon of Indian Creek, between Shoo Fly and Arlington Bridge, where the great mass of meta-augite andesite lava and tuff lies conformably between the Shoo Fly and Arlington beds and dips steeply to the southwest.

Distribution.—The same conclusion may be drawn from its general distribution northwest of Houghs Peak, where for over 20 miles it follows along the strike between the Shoo Fly and Arlington formations. Southeast of Houghs Peak, however, its distribution is somewhat less regular. It breaks across the older strata, sending dikes into them and covering them in a broader area, which extends south of the fortieth parallel for many miles.

A second and much smaller area lies between the Peale and Robinson formations, crossing Genesee Valley a mile east of the post-office. It seems most probable that the lavas of this small area, though of Carboniferous age, are somewhat younger than those of the Taylor Rock area. The Peale formation apparently belongs between them.

It seems most probable that the masses of meta-andesite west of Taylorsville, as well as that of the mounds in Indian Valley, the point northeast of Crescent Mills, and the larger mass of Keddie Ridge and Keddie Peak, belong to the Taylor meta-augite andesite. Much of it is like the Fant meta-andesite, to be described presently.

Relations to adjacent formations and age.—In considering its occurrence emphasis was placed on the fact that it lies between the Arlington and Shoo Fly formations and would therefore appear to be of contemporaneous eruption interstratified with Carboniferous rocks. Dikes have been found running off from the main mass near Taylor Rock into the Arlington formation, but not into the overlying beds to the southwest.

KETTLE META-ANDESITE.

General description.—The principal rock included under this designation is decidedly porphyritic, with many small phenocrysts of feldspar and some of hornblende, and rarely also a few round grains of quartz. These are embedded in a reddish-brown or gray, partially crystalline groundmass, containing small grains of plagioclase and quartz. This form is most abundant on the prominent spur leading from Peters up to the Lucky S mine, also in Hornfels Point and along the east slope of Wards Creek.

A subordinate but still abundant rock included in the Kettle meta-andesite is pale greenish gray and generally nonporphyritic except in thin section under a microscope where phenocrysts of feldspar are seen altered to epidote and quartz and embedded in a fine groundmass full of feldspar microlites. This form is most abundant along Peters Creek and in the neighborhood of Kettle Rock. Both these forms are intimately associated with fragmental rocks, mainly tuffaceous, but locally passing into fine conglomerate and sandstone.

Occurrence.—The Kettle meta-andesite is clearly of volcanic origin, and its mass is made up of an extended series of lava flows and products of volcanic explosions. The whole mass has been subject to much deformation, so as to obscure the original structure, but the individual sheets of lava and tuff are locally still visible on the steep, rocky canyon slopes of Peters, Surprise, and Lights creeks.

Distribution.—A small area lies south of Genesee Valley, but the main mass extends from Hornfels Point northwest across Peters

Creek and Lights Creek to Moonlight and Mountain Meadows, where it disappears mainly beneath the mass of Tertiary lavas which cap that portion of the range, and which have not been completely mapped in detail.

Relations to adjacent formations.—The relation of the Kettle meta-andesite to the Robinson, Trail, and Foreman formations, as shown on the map (Pl. III), appears at first glance to be that of an eruptive including dislodged masses of the formations named. It must be remembered, however, that of all the included masses on Hosselkus Creek, Peters Creek, North Arm, Lights and Surprise creeks, only one, that on Peters Creek, contains fossils, and they are in all probability of Carboniferous age. It is evident, therefore, that the relation of the Kettle meta-andesite to the Carboniferous sandstone on Peters Creek is the most important.

The Robinson beds of the limited locality on Peter Creek are red and gray tuffaceous sandstones with marked pencil structure and composed, as in the typical Robinson formation, almost exclusively of particles of volcanic rocks. By the trail they dip southwest at an angle of about 54°, but farther north they appear vertical and so grade into the coarser tuffaceous material by which they are bounded in all directions as to indicate that the sandstone in question is a part of the fragmental material of the great mass of Kettle meta-andesite, and that the volcanic eruptions occurred about the time the Robinson formation was deposited—that is, in the late Carboniferous. It may be noted here that in the Redding region of Shasta County, where the structural relations are much simpler, there are great masses of volcanic material at about the same geologic horizon.

Tuffaceous sandstones were found at a number of localities within the Kettle meta-andesite, but microscopic sections revealed no fossils. Some were not marked on the map, but others were, and it is possible that all may belong to the Robinson formation. This, however, does not seem probable in the areas marked as belonging to the Trail and Foreman formations, where the masses are large and the lithologic resemblance close to the nearest masses of sediments. The long, narrow belt of the Trail formation crossing Hornfels Point is vertical and appears to be folded or faulted down into the meta-andesite. In the Surprise Creek areas the rocks are like those of Evans Peak and have a gentle dip to the southwest directly into the meta-andesite, from which it is most likely separated by a fault.

On the north side of Genesee Valley the Kettle meta-andesite is converted into hornfels along its contact with the granodiorite, showing conclusively that the meta-andesite is older than the diorite. It is important to note in this connection the occurrence in the tuffaceous Kettle meta-andesite conglomerate of pebbles of red jasper and of a reddish granitic rock. The latter is composed of red orthoclase and quartz with marked graphic texture and includes a few scales of mica. The jasper may come from earlier Carboniferous rocks, but the source of the other is unknown.

REEVE META-ANDESITE.

General description.—White crystals of plagioclase are plentifully scattered in a compact dark groundmass, giving the rock a conspicuous porphyritic structure. No phenocrysts of augite are present, and the dense groundmass appears largely amorphous and is full of feldspar microlites, generally without any definite ferromagnesian silicate. In one case, however, the groundmass was found to be holocrystalline and composed of many ledge-shaped crystals of plagioclase, with grains of augite and magnetite filling the angular spaces between them as in diabase.

Though some of the material appears to be a solid lava flow, much of it is fragmental yet decidedly porhpyritic, and distinguishable from the other chiefly by the fact that it contains a variety of well-preserved fossils and grades into the sandstone of the Robinson formation. In places the rock has been so squeezed as to develop a slaty structure, in which the phenocrysts of feldspar are drawn out long in the plane of cleavage.

Occurrence and distribution.—It occurs as a definite flow and tuff which forms a long, narrow belt running northwest from Robinson's house in Genesee Valley and bounded on both sides by fossiliferous beds of the Robinson formation. A remarkable expansion of this area occurs a mile northwest of Robinson's and is succeeded in the same direction by a narrow dikelike mass which is remarkable for its schistosity, suggesting that its narrowness is due to compression.

A second belt similar to the first borders the Robinson formation on the west, but its long, slender, dikelike south end does not quite reach Genesee Valley. South of Genesee Valley a small area of the Reeve meta-andesite occurs east of Wards Creek.

North of Indian Valley four areas occur (Pl. II) which have not been mapped in detail. The first and principal area is a long, narrow belt extending northwest from near the Lucky S mine to Moonlight; the second is at the head of Cooks Canyon, and the other two lie on the slopes east of Mountain Meadows in line with the principal mass already noted.

Relation to adjacent formations and age.—The intimate association of the lava and tuff with the Robinson formation, into which the tuff grades, as well as the fossils contained in the tuff, fixes the age of the igneous eruption as in the late Carboniferous. The long southern extremity of the western area has the form of a dike cutting the earlier meta-augite andesite, which may belong to the same horizon as that of

Taylor Rock, though it seems to be somewhat later in the Carboniferous. These horizons of vigorous volcanic activity in the Carboniferous correspond closely to those of the Redding region of Shasta County described in the Redding folio.

The relation of the Reeve meta-andesite to the Kettle meta-andesite is not clear, though it appears to penetrate the volcanics as a dike, indicating that the Kettle meta-andesite is the older.

JURASSIC.

FANT META-ANDESITE.

General description.—The Fant meta-augite andesite is a greenish to reddish-brown rock which is more or less porphyritic, sometimes with augite, but often with plagioclase in a groundmass made up of small crystals and grains of feldspar, augite, and magnetite, and generally with some amorphous matter. Occasionally it is conspicuously porphyritic with an abundance of greenish crystals of plagioclase in a reddish groundmass. When the phenocrysts are of augite they are inconspicuous in a greenish groundmass. The most abundant form of this meta-augite andesite is fragmental, and it is composed of material ejected by volcanic eruption, so that it is tuffaceous. It is generally fine, the fragments being under an inch in diameter and often amygdaloidal.

Occurrence and distribution.—The Fant meta-augite andesite occurs in flows, forming with its associated tuff irregular layers parallel generally to the stratification of the adjoining sedimentary rocks. The flows and tuffs being irregular, it is difficult to determine their general position, but where best exposed they dip to the southwest.

It forms a broad belt extending a little west of north from the lower slope of Grizzly Mountains across the western slope of Mount Jura to North Arm of Indian Valley. The south half of the belt is narrow, but the north half is wide and irregular.

Relation to adjacent formations and age.—Along the west slope of Mount Jura at a number of points the Fant meta-augite andesite contains included fragments of the adjacent Hardgrave sandstone, so there is no reasonable doubt that the meta-augite andesite is younger than the Hardgrave sandstone, though in the overturning of the Jurassic strata on Mount Jura the Hardgrave sandstone was placed on top of the meta-andesite.

On the other hand, this overturning of the Jurassic rocks has brought the meta-andesite on top of the Thompson limestone. At both the north and the south end of Mount Jura, as well as on its western slope directly south and southwest of the summit, the Fant meta-andesite lies between the Hardgrave sandstone and the Thompson limestone, and while it contains fragments of the former the contact with the latter is such as to show the deposition of the limestone on the meta-andesite. This portion of the meta-andesite is of volcanic effusion during the early Jurassic in the interval between the deposition of the Hardgrave sandstone and the Thompson limestone.

HULL META-ANDESITE.

General description.—This greenish to reddish meta-andesite is like the Fant meta-andesite just described, though the fragmental phase and the porphyritic phase rich in feldspar phenocrysts are relatively not so abundant. The prevailing type is greenish and essentially nonporphyritic, and occasionally in the Little Grizzly Creek region it is decidedly amygdaloidal.

The rock in general is only partially crystalline and is made up essentially of plagioclase and augite or their alteration products, chiefly epidote, chlorite, and some quartz. In a few cases it was found wholly crystalline, with the angular spaces between the crystals of plagioclase filled with augite and magnetite as in diabase. In a few cases also, especially in the dikes cutting the metarhyolite, it contains primary granular quartz in the groundmass as in the quartz-augite diorites.

Occurrence and distribution.—Much of it is in more or less well-defined sheets representing lava flows and tuff and is exposed in the neighborhood of Little Grizzly Creek, where the older rocks are generally covered. The mass which splits the belt of Peale beds southeast of Genesee is intruded between the strata. North of Indian Creek the mass narrows and becomes dikelike. It is decidedly slaty and near the divide cuts across the belt of Peale beds as well as the later formations to the east. More definite dikelike masses occur on the north and south slopes of Mount Jura, and it is possible that it occurs also as dikes within the area marked as Fant meta-augite andesite but was not recognized. Definite dikes occur also cutting the metarhyolite and sedimentary rocks just north of Tower Rock and elsewhere along the slopes of Grizzly Mountains.

Relation to adjacent formations and age.—The fact that it penetrates the Mormon sandstone, and especially also the Foreman beds northeast of Mount Jura, indicates that its eruption took place after the deposition of the Foreman formation and most likely near the close of the Jurassic.

LATE JURASSIC OR EARLY CRETACEOUS.

SERPENTINE.

General description.—Much of the material included under this designation is typical green serpentine which readily splits up into slickensided lenticular pieces, but it contains nodules and large masses of a prevailingly dark rock with the texture of granite but exceedingly tough. This rock is enveloped and permeated with serpentine and shows the rock from which the serpentine was derived by alteration. It varies greatly in composition. The most abundant form is composed almost wholly of a light-colored pyroxene with a small amount of dark-green hornblende. Occasionally the hornblende increases and plagioclase appears, so that the rock passes into phases related to gabbro or diorite, though it is for the most part a pyroxenite. Serpentine is frequently derived from peridotite—that is, a rock rich in olivine—but in the serpentines of the Taylorsville region no definite trace of olivine was found.

Distribution, relation to other rocks, and age.—The serpentine of the Taylorsville region occurs in irregular stocks like that of Grizzly Mountains and Round Valley Reservoir, but may be elongated like that of Montgomery Creek or run out into long, narrow dikes like those of the east slope of Grizzly Mountains. The serpentine intersects the metarhyolite of Grizzly Mountains and all the Paleozoic rocks with which it is associated in the Taylorsville region, but does not come in contact with later sediments. On the other hand, the serpentine is cut by quartz diorite and dikes of the later rhyolite, and belongs among the first eruptions of the late Jurassic or early Cretaceous.

GRANODIORITE.

General description.—The rock included under this head is a light-colored and for the most part medium-grained rock which looks like granite. It is composed chiefly of plagioclase feldspar and quartz, with a small amount of dark-green hornblende and black mica and a trace of orthoclase, magnetite, pyroxene, and other accessory minerals. One of the best exposures of this rock is by the road near Flournoy's, at the head of Genesee Valley. At different localities the relative proportions of the minerals named above vary greatly. The rock is generally quartz diorite, but locally the orthoclase may increase and the rock passes into granodiorite. Pyroxene occasionally becomes prominent near the borders of the mass and the rock passes into quartz-pyroxene diorite, a good example of which occurs on the Cosmopolitan mine road, 2 miles west of Flournoy's. The abundance of pyroxene and the almost complete absence of quartz gives this finer grained rock a darker color than that of Flournoy's. Another variation which is peculiar in containing tourmaline occurs south of Moonlight. It is dark colored and fine grained, with considerable quartz and much hornblende, sometimes grouped so as to make the rock dark spotted. The dark-brown tourmaline is not prominent in the hand specimen but becomes so in thin section, where the crystals are seen to be grouped with radial arrangement.

Occurrence and distribution.—The quartz diorite and granodiorite which form the bulk of the north end of the Sierra Nevada east and northeast of Genesee Valley are part of the great mass of the range farther south. Their apparently irregular distribution is due to the partial cover of Tertiary volcanics. Near the head of Mountain Meadows is a mass of quartz diorite, which is separated into several areas by auriferous gravel. It is rich in quartz and hornblende, and fine grained like that along the western border of the great mass about Lights Canyon. Several isolated dikelike masses occur, one along Houghs Creek southwest of Taylorsville, between the Taylorsville and Arlington formations, and another northeast of Crescent Mills, where it cuts metarhyolite. A small round mass cuts the serpentine southwest of Greenville, and a similar but smaller mass occurs near the fortieth parallel in the Kettle meta-andesite.

Relation to adjacent formations and age.—On the north side of Genesee Valley the quartz diorite comes in contact with the Swearinger slate, the Trail formation, and the Kettle meta-andesite. Along the contact the quartz diorite has locally converted adjacent portions of all these formations into dark flinty hornfels, which is abundant in places along the crest of Hornfels Point. While it is certain that the irruption of the quartz diorite took place after the deposition of the Trail formation, its relation to the other Jurassic formations in the Taylorsville region could not be determined. In the Downieville region, however, Turner has shown that the irruption occurred after the deposition of the Milton formation, which is equivalent to at least part of the Taylorsville Jurassic.

As to its neighboring igneous rock, the quartz diorite is clearly younger than the Kettle meta-andesite and the metarhyolite which it intersects, but in the canyon north of Round Valley Reservoir it is cut by dioritic dikes, which must be considered the younger.

VARIOUS DIKE ROCKS.

General description.—The most common dike rock varies in color from light gray to pale green and reddish brown. Small phenocrysts of quartz are always present, but it is rarely porphyritic, except in the reddish-brown form, which is full of phenocrysts of feldspar. It is rhyolite, but lacks entirely the brecciated feature which is so generally prominent in the metarhyolite, and in but few localities does it show fluidal structure.

Another form, which has no quartz phenocrysts and looks much less siliceous, is made up almost wholly of plagioclase and green hornblende. It is a fine-grained greenish diorite. The occurrence and distribution of the rhyolite will be considered first and then that of the diorite.

Occurrence and distribution.—The forms are distinct dikes and small circular or angular patches. One and a half miles west of Greenville there are a number of dikes running a little west of north through a small area of banded slates belonging to the Taylorsville formation. The largest of the dikes is about 75 feet in width, but could not be traced more than a mile along the strike.

From Round Valley Reservoir, about one-third of the way down North Canyon to Greenville, the granitic rock is intersected by a dikelike mass of rhyolite nearly 100 feet in width. It forms prominent cliffs and falls along the stream. Just below the Phœnix Mill the dike strikes nearly east and west. Locally the rock looks like a microgranite, and under the microscope shows remarkable graphic intergrowths of quartz and feldspar.

A mile and a half west of Taylorsville there are four dikes and irregular patches of rhyolite apparently cutting the meta-augite andesite and Taylorsville formation, while 2 miles south of Taylorsville distinct dikes of rhyolite occur in serpentine.

On the west slope of Mount Jura there are a number of small masses of rhyolite. Those associated with small areas of Hardgrave sandstone have been derived by faulting from the large mass to the west, but some of the others appear to be intrusive in the meta-andesite. The most distinctive mass, nearly circular in outline, occurs about a mile southwest of the summit of Mount Jura. The rock is reddish brown in color and decidedly porphyritic, with many small crystals of feldspar and quartz. The quartz is rounded and embayed, and the feldspar is at least in part plagioclase and generally much altered. Microscopic traces of altered hornblende are scattered through the groundmass. The relations of this mass to the adjacent meta-andesite were not clearly made out, but it is believed that the rhyolite penetrates the meta-andesite.

A short distance farther south is a dikelike mass of rhyolite nearly a mile in length. The rock is greenish and nonporphyritic, like the dikes in the serpentine, and appears to hold the same relation to the meta-andesite as the porphyritic type just noted.

Half a mile northwest of the summit of Mount Jura is a mass of rhyolite cutting across a belt of meta-andesite that intersects the Mormon sandstone, and near the center of section 24, 2½ miles northeast of Taylorsville, is a small mass lying between the Mormon sandstone and meta-andesite. A third mass, about a mile north 10° east from the summit of Mount Jura, penetrates the Foreman beds. All three masses are long and narrow and appear to be dikes, but on the divide east of Mount Jura, at the head of Hinchman Ravine, is another circular mass similar to that on the west slope of Mount Jura. It penetrates the Peale formation of Carboniferous age as well as the associated meta-andesite, and is remarkable locally on account of its distinct fluidal structure. A similar mass, holding essentially the same relations to adjacent rocks, occurs on Little Grizzly Creek near the fortieth parallel.

The dikes of diorite were noted in the canyon north of Round Valley Reservoir. They are vertical, range from 5 to 10 feet in width, strike nearly north and south, and cut directly through the lighter-colored, coarser-grained granitic rock. Their relation to the dike of rhyolite in that vicinity was not satisfactorily determined.

Relation to adjacent formations.—In considering their occurrence and distribution the relations of the rhyolite and diorite dikes to adjoining rocks in each locality were brought out, and they appear to intersect sediments belonging to Silurian, Devonian, Carboniferous, and Jurassic formations, as well as meta-andesite, serpentine, and granodiorite among igneous rocks. They are evidently of late Jurassic or early Cretaceous intrusion. This relation to sedimentary and igneous rocks distinguishes the rhyolite dikes from the meta-rhyolite, which is of early Paleozoic volcanic effusion.

MIOCENE.

RHYOLITE.

General description.—Rhyolite is a siliceous lava, generally light colored or brownish and more or less porphyritic, with grains of quartz and sometimes with scattered crystals of feldspar or biotite. All of these forms occur in the Taylorsville region in the small areas on the ridge west of Shoo Fly and half a mile south of Greenville. Perhaps the most definite rhyolite masses of the Taylorsville region are tuffs which occur in the auriferous gravels near the head of Willards Creek, 10 miles southwest of Susanville. They are grayish white and composed almost wholly of splinters and pumiceous fragments of volcanic glass. The following chemical analysis of it was made years ago by George Steiger and published in United States Geological Survey Bulletin No. 228, page 211:

Analysis of rhyolitic tuff from Willards Creek, near Susanville, Cal.

SiO_2	70.01	K_2O	5.12
Al_2O_3	12.61	H_2O at 100°	2.37
Fe_2O_3	1.47	H_2O above 100°	4.68
FeO	.50	P_2O_5	.04
MgO	.72	MnO	Trace.
CaO	1.06		
Na_2O	1.94		100.52

Distribution and relations.—On the ridge west of Shoo Fly are two small areas of rhyolite. They differ somewhat in color, yet possibly belong to the same flow. At the southern locality the rhyolite apparently overlies gravel and is itself overlain by a flow of basalt.

South of Greenville is a small mass elongated nearly north and south and not far from the course of the line which connects the other two detached masses. It is possible, but not probable, that all these small masses are remnants of the same flow.

Some rocks which may be rhyolitic were noted during a reconnaissance along the road in Last Chance Valley and on the eastern crest between the road and McKesick Peak. The rock is generally tuffaceous, coarser than that already noted, and not clearly rhyolitic. It lies directly on the granodiorite and is overlain by basaltic flows.

South of the fortieth parallel, in the region mapped by Lindgren and Turner, rhyolite and rhyolitic tuff are more abundant, and they directly overlie the earlier auriferous gravel. The same horizon is probably represented by the rhyolitic tuff on Willards Creek, which, on account of the smallness of the area, is included on the map (Pl. II) in the auriferous gravels.

PLIOCENE.

ANDESITE.

General description.—Andesite is a lava, usually light gray, which, though not generally porphyritic in the hand specimen, becomes more or less clearly so in thin section. Crystals of plagioclase are numerous; those of hornblende, biotite, and pyroxene are somewhat less abundant but in various proportions. The felty dark gray groundmass inclosing the phenocrysts contains many minute microlites of feldspar and black grains of magnetite in a light-brown glassy base.

In some cases the hornblende phenocrysts are abundant, surrounded by dark borders, and the rock is a typical hornblende andesite. In other cases hornblende is practically absent and pyroxene is the characterizing mineral. All these forms are generally accompanied by a great deal of andesitic breccia and tuff from explosive volcanic action.

Occurrence and distribution.—It occurs in sheets, forming a blanket covering the older rocks around the volcanic vent from which the flows and ejected material issued. There were many vents, and the cover was continuous over a large part of the region. Erosion has removed the cover in places and left isolated patches, sometimes revealing the volcanic necks through which the material reached the surface. This is especially the case in Lone Rock, which is a conspicuous peak surrounded by cliffs. A less conspicuous example occurs in Indian Creek, between Lone Rock and Thompson Peak. Both of these masses are of hornblende andesite, closely related to that north of Kettle Rock, as well as the isolated patches near Hosselkus Valley, on Hornfels Point, and on the divide at the head of Foremans Ravine.

The andesite by the chalybeate soda spring near Arlington Bridge is black and breaks with very irregular fracture. It is slightly porphyritic with crystals of plagioclase embedded in a groundmass full of small lath-shaped feldspars with grains of augite embedded in a dark globulitic base. The lava came down from the slope a short distance south. The andesite overlying the gravel a mile northeast of Greenville is much richer in augite and poorer in amorphous matter than that of the Arlington spring. Its source is not definitely known, but it probably issued from a vent at the southeast end of the exposure.

The large continuous sheet of volcanic rocks along the fortieth parallel, about the heads of Squaw and Last Chance creeks, is in part hornblende andesite, with some pyroxene andesite and a smaller proportion of basalt and rhyolite which has not been mapped separately.

The andesitic tuff and breccia which form Diamond Mountain are full of black-bordered hornblende, but in Red Mountain the hornblende has largely disappeared and the prevailing ferromagnesian silicate is pyroxene.

The area between Moonlight and Mountain meadows is mainly hornblende andesite on the eastern side and pyroxene andesite on the western slope, though the two are intermingled. The same is true of the Cheney Creek area and the small area north of Nanney, but the larger mass which forms the end of this part of the Sierra Nevada is almost wholly pyroxene andesite.

North and east of Susan Creek much of the country has not been seen. A general reconnaissance was made by J. Stanley-Brown in 1890. Hot Springs Peak, an old volcano, was visited and is known to be andesite, though the rocks about its north base are basalt. Shaffer Peak is supposed to be of the same character.

Relation to adjacent formations and age.—North of Kettle Rock, about the head of one of the tributaries to Lights Creek, the andesitic breccia overlies auriferous gravel, and the same is true north of Moonlight, where the auriferous gravel, firmly cemented, dips westerly beneath the andesites which form the crest. The andesites and andesitic breccias in the Taylorsville region, like those of other portions of the Sierra Nevada, overlie the earlier auriferous gravels.

The earlier auriferous gravels contain many pebbles of igneous rocks derived in large measure from the Paleozoic and Mesozoic lavas already described, which are so widely distributed about the north end of the Sierra Nevada. The early gravels contain also some fragments of lava which appear less altered than those just referred to, but exposures of such lavas were not definitely recognized and distinguished from the Tertiary lavas which overlie the older gravels.

On the other hand, as explained under "Auriferous gravels," the later gravels overlie andesitic flows and are composed in some cases almost wholly of andesitic pebbles. It seems evident, therefore, that the eruptions of andesite occurred within the gravel period, overflowing the earlier gravels and furnishing the material for the later gravels.

QUATERNARY.

BASALT.

General description.—Basalt is lava which is generally darker colored, more compact, and heavier than andesite, and, though not plainly porphyritic, yet, unlike the andesite, it frequently contains visible grains of yellowish-green olivine. In thin section it is seen to be composed chiefly of plagioclase and augite and a smaller proportion of olivine and magnetite. The dark-gray forms are holocrystalline, but the darker, compact ones have, besides the more or less abundant crystals of plagioclase, much black amorphous matter instead of augite.

Occurrence and distribution.—Basalt is somewhat less abundant than andesite in the Taylorsville region. Like andesite, it occurs generally in flows about a volcanic vent. Mount Ingalls, just south of the fortieth parallel, is a large volcano built up almost wholly of basalt. Turner has shown in the Downieville folio that Mount Ingalls is made up of earlier and later basalts, separated at least in part by a mass of andesitic tuff. The later basalt forms the bulk of the mountain and extends north over the quartz diorite to near Genesee Valley. It is dark gray, holocrystalline, and rich in augite. The earlier basalt appears along the road south of Flournoy's. It is black and compact and contains much amorphous matter. At this point the two basalts are not separated by andesite, and they are not distinguished on the map of the Taylorsville region for the reason that the subdivision of earlier and later can not be applied throughout the region. For example, the youngest basalt of the region is a flow which followed Susan Creek for miles. It is later even than the later basalt of Mount Ingalls and yet most like the older basalt.

One of the finest exposures of basalt in the region occurs at Thompson Peak, opposite Janesville. The eastern slope of Thompson Peak is a steep bluff exposing a succession of basalts and tuffs in layers from 5 to 30 feet thick dipping gently to the southwest. The exposed thickness is apparently about 1,200 feet, and the lower flow in contact with the quartz diorite is very dark and compact, like the earlier basalt of Mount Ingalls. Some of the succeeding layers are vesicular, rich in olivine and much black globulitic base instead of augite. The summit of Thompson Peak is of holocrystalline basalt, with considerable olivine, but rich in augite occupying the angular spaces between the lath-shaped crystals of plagioclase.

Beneath Thompson Peak, on the slope toward Janesville, there are numerous dikes of basalt cutting the diorite. Some run nearly parallel with the crest of the range, and others in various directions, as if Thompson Peak were a volcanic center from which they radiated.

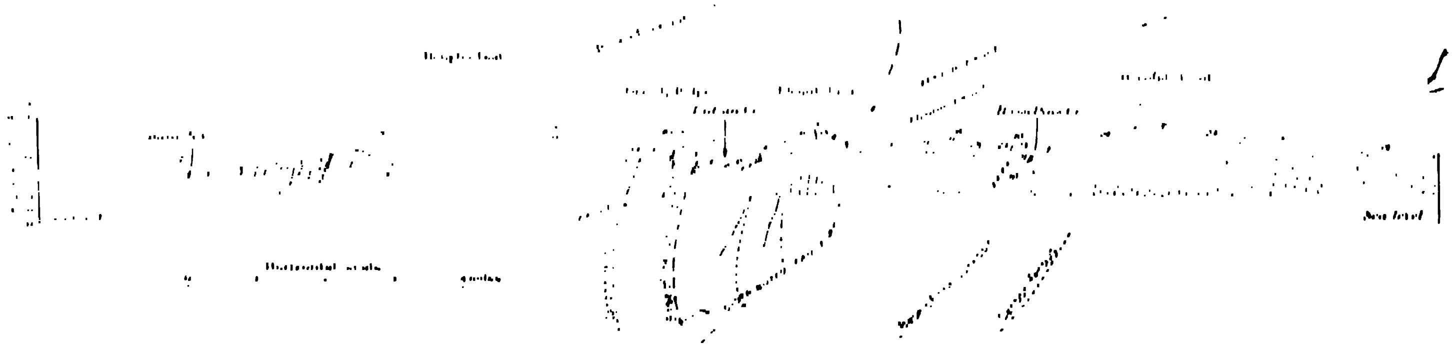

FIG. 11.—General section of [illegible]. *Sedimentary*: [illegible] 1, [illegible] formation; 2, Hinchman sandstone; 3, Bicknell sandstone; 4, Mormon sandstone; 5, Thompson [illegible] Trail formation [illegible] Swearinger slate (does not appear on line of section); 9, Hosselkus limestone. Carboniferous: 10, [illegible] group (a, [illegible] formation; b, [illegible] formation; c, Arlington formation). Devonian: 12, Taylorsville formation. Silurian: 13, Montgomery [illegible]. *Igneous*: Quaternary: [illegible] Basalt [illegible] 16, Andesite; 17, rhyolite. Late Jurassic (early Cretaceous): 18, Various dikes, [illegible] Carboniferous: 23, Reeve meta-andesite; 24, Kettle meta-andesite; 25, Taylor meta-[illegible]

A number of small areas of basalt occur on the steep slope of the Sierra Nevada north of Thompson Peak, but the most interesting area is a small one on the very crest, a short distance south of Diamond Mountain. This little mass, not a hundred yards long east and west, lies nearly flat across the crest and ends in a bluff on the east. It is somewhat amygdaloidal, with definite flow structure from the east, and in this respect agrees with the flow structure seen in some of the flows exposed on the northeast slope of Thompson Peak.

The largest area of basalt is that which surrounds and covers the end of the range north of Mountain Meadows and in succeeding flows descends the valley of Susan Creek. It is part of the great flow which descends from the region of Lassen Peak. There may be other large areas of basalt east and southeast of Susanville, but the hasty reconnaissance of that region by J. Stanley-Brown did not permit the detailed separation of them from the andesites.

As already stated, the latest basalt flow of the Taylorsville region is that which follows the course of Susan Creek. Others have followed watercourses, but their preservation is far less complete. Remnants of successive flows widely separated in time occur in the Shoo Fly region. On the crest of the spur west of Shoo Fly are two remnants of an old basalt flow in part covering rhyolite. At several lower levels are lava-capped benches which are remnants of successive flows that have occupied the bed of Indian Creek and been almost wholly removed by erosion.

STRUCTURE.

GENERAL STATEMENT.

The general structure of the Taylorsville region, as far as its sedimentary rocks are concerned, is shown in the accompanying (measured) section (fig. 11), which represents a tract 17 miles in length. Beginning on the southwest, at an elevation of 3,100 feet on Spanish Creek, it crosses Houghs Peak at 7,254 feet, and reaches Indian Creek, 1½ miles above Taylorsville, at an altitude of 3,500 feet. Continuing in the same course, it crosses Mount Jura at 6,000 feet about one-third of a mile south of the summit. The upper portion of Hinchman Ravine and other small ravines are crossed to reach Hosselkus Creek, 2¾ miles above Genesee, at an elevation of 4,050 feet. Thence the section passes over the northern portion of Hornfels Point at an elevation of 6,500 feet and skirts along the top of the southern slope of the mountain, whose summit is 3 miles directly north of Flournoy's.

The strike of the rocks throughout the region is N. 5° to 65° W., and the dip, with rare exceptions in the Shoo Fly and Foreman formations, is toward the southwest at angles varying from 39° to 75°.

The region traversed by the section may be divided into three belts: (1) The Mount Jura or middle belt, characterized by overturned strata; (2) the Grizzly Mountains or west belt, in which the strata are not overturned; and (3) the east belt, of diorite, which forms the eastern part of the range.

MOUNT JURA BELT.

The Jurassic strata of Mount Jura have been completely overturned. Their general dip is to the southwest. The Hardgrave sandstone lies on top, with the Thompson limestone, Mormon sandstone, Bicknell sandstone, Hinchman tuff, and Foreman beds in a descending but successively younger series dipping beneath the Hardgrave sandstone. This order of superposition is well exposed on the west slope of Mount Jura, and also on the slope toward Hinchman Ravine. The formations are all well characterized by fossils. As there can be no question concerning their relative age determined by Professor Hyatt, it is evident that they have been overturned.

The overturning involves also the Triassic and Carboniferous strata east of Mount Jura on Hosselkus Creek, where the Trail beds of the Jurassic dip beneath the Swearinger slate and Hosselkus limestone of Triassic age, and these in turn dip beneath the Robinson formation of Carboniferous age.

The belt of overturned strata, embracing those of Mount Jura, after which the belt is named, and the country to the east as far as Hornfels Point, is 6 miles in width. The strata involved have a thickness of about 9,000 feet. All of the strata in this belt are overturned toward the northeast, and this is evidently the result of a great thrust from the southwest.

GRIZZLY MOUNTAINS BELT.

The Grizzly Mountains belt of strata, lying southwest of Indian Creek, is over 12 miles in width in the Taylorsville region and extends beyond its limits. The oldest strata, those of the Grizzly formation, are Silurian, and they dip to the southwest. They are overlain in regular succession by the Montgomery limestone, Taylorsville formation, and Arlington beds, all Paleozoic, and also by a great mass of interbedded volcanics, succeeded by the Shoo Fly formation of Carboniferous age. The whole mass has a thickness of over 14,000 feet. The dip between Indian Creek and Houghs Peak is not over 45°, but west of the volcanics, in the Shoo Fly formation, the dip is increased and may be reversed to a limited extent by local causes. On the whole, this belt is strongly contrasted with that of Mount Jura in that the sedimentary rocks of the Grizzly Mountains belt are older than the middle Carboniferous, are only moderately disturbed, and occur in regular succession, while those of the Mount Jura belt are all younger and much disturbed with interrupted succession.

GRIZZLY MOUNTAINS ANTICLINE.

The Grizzly Mountains belt of strata dipping to the southwest appears to be one arm of an anticline of which the other arm has disappeared. The anticline was overturned toward the northeast by thrust from the southwest. Continued thrusts broke the arch and gave rise to an overthrust fault on which the southwest arm of the anticline appears to have been shoved up over the northeast arm, as shown in the section in fig. 11. This movement and consequent erosion brought to the surface the metarhyolite upon which the Hardgrave sandstone was deposited in the early Jurassic.

MOUNT JURA SYNCLINE.

Adjoining the Grizzly anticline upon the northeast is the Mount Jura syncline, a region of subsidence which may have continued an area of deposition long after deposition ceased over the crest of the

Grizzly arch, and thus became filled with strata which have no equivalents in the Grizzly arch or on the southwest slope of the Sierra Nevada.

The earliest evidence of this sort concerning the Mount Jura syncline is the presence of the Robinson formation, which is the latest Carboniferous known in the Sierra Nevada, and which lies northeast of the main crest of the Sierra Nevada chiefly in the Mount Jura syncline, and indicates that the Mount Jura syncline may have begun as early as the Carboniferous. Later the same region of depression received an extensive series of Triassic and Jurassic deposits not found west of the main crest at the north end of the range.

The thrust from the southwest which overturned and faulted the Grizzly arch overturned the adjoining arm of the Mount Jura syncline. In Mount Jura and the country to the east, including Hornfels Point, there is no repetition of strata, a feature which indicates that all belong to the southwest arm of the syncline, for all are included in the overturning. The relation of the adjoining portions of the Grizzly anticline and the Mount Jura syncline, though well exposed in the line of the general section (fig. 11), may be seen to advantage 2 miles farther southeast, where several patches of Hardgrave sandstone occur on the lower slope of Grizzly Mountains.

The structure of the syncline is not as simple as it was formerly supposed. The irregularity in the distribution of the Carboniferous, Triassic, and Jurassic within the syncline may be attributed to the folding of the Carboniferous, and later of the Triassic, before the Jurassic strata were deposited.

The entire disappearance of the Jurassic portion of the eastern arm of the syncline is most probably due, as shown in the section, to a large amount of distributed thrust faulting—the Hull fault, that gave rise to the prominent slaty structure in the mass of Hull meta-andesite which separates the youngest Jurassic (1) from the Carboniferous (11, *a*). This igneous rock appears to have been intruded diagonally into the syncline and afforded a plane of easy displacement to relieve the strain in that greatly compressed mass.

TAYLORSVILLE FAULT.

The fault developed between the Grizzly Mountains arch and the Mount Jura syncline lies near Taylorsville and follows approximately the eastern border of the metarhyolite from the lower slope of Grizzly Mountains through the canyon of Indian Creek above Taylorsville and along the eastern slope of Keddie Ridge, as indicated on Pl. III. The metarhyolite a mile northeast of Taylorsville is greatly crushed and evidently marks the course of the fault.

This fault appears to have been a line of displacement during the latter portion of the Carboniferous and to have aided in large measure in bringing the metarhyolite to the surface, so that in the Jurassic the Hardgrave sandstone was deposited on the same rock which received the Grizzly quartzite in the Silurian.

It was motion along essentially the same narrow zone that folded and overturned the strata in the Mount Jura syncline. Of this there is proof in the southern slope of Mount Jura, where the Hardgrave sandstone, Thompson limestone, and Mormon sandstone, with the associated metarhyolite and Fant meta-augite andesite, are repeated by a fault in the same order and position. This displacement followed the overturning, for the fault enters the overturned beds and shoves them along farther in the same direction.

The hade of the Taylorsville fault appears to be about the same as the west slope of Mount Jura, where some faulted masses cling to the slope dipping southwest into the base of Grizzly Mountains, but toward the summit of Mount Jura the fault plane enters the mountain and passes through to the other side, emerging at the base of the Mormon sandstone. The faulted mass is over 2 miles in length and half a mile in width, and much lower at the southern than at the northern end.

The amount of displacement on the Taylorsville fault near the close of the Paleozoic may have been great, but no data are available for its estimation. As to the post-Jurassic faulting along this line, the amount can be measured in miles, for a large part of the movement was involved in the overturning, and after the overturning was complete the movement on the fault was about a mile.

The Taylorsville fault does not extend far southward. No movement in its line was detected by Turner south of the fortieth parallel, and it is of importance to note that in the Downieville quadrangle all the Jurassic strata lie east of the axial line of the Grizzly anticlinal, and what is of greater significance is that they all dip to the east; that is, they have not been overturned like those of the Taylorsville region.

Near the fortieth parallel an ancient stream bed of auriferous gravel crossed the line of the fault, but has suffered little if any dislocation at that point, though elsewhere in the same region there has been extensive faulting since the gravel period.

HULL FAULT.

The Hull fault is a branch of the Taylorsville fault and circumscribes the mass of Mount Jura on the east. It follows the Hull meta-andesite throughout the greater part of its course from the fortieth parallel northwest to North Arm. The fault adjusts the overturned Jurassic strata on the west to the Carboniferous on the east and is expressed in the decided slaty structure of the Hull meta-andesite.

HONEY LAKE FAULT.

In the neighborhood of Honey Lake the Sierra Nevada is bounded on the northeast by a prominent escarpment due to faulting. The escarpment, about 2,000 feet in height, is composed of quartz diorite, which is overlain on the crest by auriferous gravel with a local capping of andesitic breccia in Diamond Mountain, as illustrated in fig. 10. Lava and gravel similar to those of the summit are found locally along the foot of the escarpment, but in most places they are covered by later deposits. Following the escarpment northwest to Gold Run, where the wagon road crosses the range, the gravel is found to be firmly cemented and bent down over the eastern slope of the range so as to connect that of the mountain crest and foot. The escarpment ends at this point and the fault by which it was produced passes into a monoclinal fold. The fold continues to the northwest in the old lavas of the region for about 12 miles and then disappears beneath the newer lavas from the vicinity of Lassen Peak.

From the fact that the Honey Lake fault passes into a monoclinal fold, it is evidently a normal fault and strikingly unlike the Taylorsville fault. The total displacement of the Honey Lake fault is at least 2,000 feet and may be somewhat greater, and it is clearly later than the auriferous gravels and andesitic flows of the Diamond Mountain region.

To the southeast, as shown in Pl. I, the Honey Lake fault extends through a portion of Long Valley into Nevada, where it apparently turns more to the south and possibly connects more or less directly with the main fault along the east front of the Sierra Nevada, which Lindgren has traced as far north as Reno.

In the Truckee region Lindgren has recognized three faults, approximately parallel. The main fault, the one just referred to, lies close along the eastern front of the range from Markleeville to Reno. The other two (see Pl. I) are farther west, one on either side of Lake Tahoe, and bound the sunken area or moat, as Lindgren[a] appropriately designates it, which extends as far northwest as Sierra Valley. East of Lake Tahoe is a prominent ridge or "buttress" which extends up between the Tahoe moat and the sunken region of the Great Basin.

According to Lindgren, these faults were formed during the early Cretaceous. On the eastern fault there was a displacement of 3,000 feet in the early Cretaceous, followed at the close of the Miocene by a displacement of 2,000 feet. This final movement in all probability was contemporaneous with the faulting along Honey Lake.

It is probable that movements along that fault have taken place in recent times, if earthquakes may be accepted as evidence in that direction. A few years before 1885 there were a number of small earthquakes whose region of greatest intensity lay along the foot of the Honey Lake escarpment, particularly at Janesville, where objects were thrown from the walls and mantles in dwellings and chimney tops were overthrown. Although the earthquakes were probably due to slight movement along the old fault plane, yet no fissures were visible on the surface, as was the case along Inyo Valley after the great earthquake of 1872.

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[a] Jour. Geology, vol. 4, 1896, p. 895.

MOHAWK VALLEY FAULT.

The fault along the west side of Lake Tahoe (Pl. I) Lindgren has traced northwest from Mount Tallac by way of Donner Lake, Lake Independence, and Webber Lake up toward the southwest corner of Sierra Valley and Mohawk Valley, where it has been studied in detail by Turner, who remarks in the Downieville folio that—

> The best evidence that a great displacement has occurred here in Tertiary time consists of the presence of river gravels on the high plateau to the west. At one point about 2½ miles northwest of Haskell Peak there is a heavy mass of well-rounded gravel at the very edge of the escarpment, and a considerable portion of this mass has by gravity traveled down the slope, so that the apparent thickness of the deposit is about 500 feet. To the northeast and west of Haskell Peak, and also close to the edge of the escarpment, are smaller masses of similar gravel, all of them capped with rhyolite and all at an elevation of about 7,000 feet. It is evident that we have here remnants of an old river deposit formed by a stream flowing at a moderate grade. It is not likely that such a stream could have existed along the edge of a plateau having a steep escarpment. There can be no reasonable doubt that since these gravels were deposited a profound displacement has occurred, in virtue of which that portion of the former plateau lying to the east of the present escarpment has dropped down 2,000 or more feet and now lies buried beneath the sediment of the former Mohawk Lake and beneath the Tertiary lavas.

An earthquake occurred in this valley in 1876, which resulted in forming a fissure 2 feet wide and invigorating a number of hot springs along the line of the former fault.

Northwest of Mohawk Valley Turner has found fault scarps at a number of points, but especially along Spring Garden Creek and farther west along the base of Spanish Peak in Meadow Valley, where there appears to have been a displacement of 3,000 feet since the deposition of the auriferous gravels. This fault has been referred[a] to as the American Valley fault. Continuing northwest in the line of the faulting across North Fork of Feather River, about the head of Chip Creek, several faults occur in the lavas of the Lassen Peak region. Forty miles farther northwest, in the same line which passes to the west of Lassen Peak, a low arch in the older rocks comes out from under the lavas and crosses Pit River into the Klamath Mountains about 20 miles northeast of Redding. This line of displacement appears to be the one connected with the main crest of the Sierra Nevada, and its influence was felt in the Klamath Mountains.

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[a] Bull. U. S. Geol. Survey No. 33, 1886, p. 13; Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 426.

The length of this faulted belt (shown in Pl. I) from Lake Tahoe to beyond Spanish Peak is over 50 miles, and to Pit River nearly as far again. Though a definite fault line can not be traced all the way, there are places where it is evident. In the Lake Tahoe region, as shown by Lindgren, the faulting on this line occurred chiefly, if not wholly, in the early Cretaceous, but in Mohawk Valley and farther northward the faulting appears to have been chiefly, if not wholly, later than the gravels. The arch, which in the Redding folio is called the Copper City arch, is bordered by fossiliferous rocks which show it to have been formed after the Chico and before the Ione. It is likely, therefore, that the early Cretaceous movement which Lindgren recognized about Lake Tahoe reached the Klamath Mountains about the close of the Cretaceous, but that the greatest amount of displacement along that line in the north end of the Sierras took place after the earlier gravel period.

INDIAN VALLEY FAULT.

Having traced the Honey Lake fault from its north end, where it passes into a monoclinal fold, southeast to the neighborhood of Reno, and the Mohawk Valley fault from Lake Tahoe to the lavas of Lassen Peak and beyond to the Klamath Mountains, let us turn our attention to the line of faulting that lies between the two already noted.

Lindgren has traced a fault from the eastern side of Lake Tahoe northwest across the Truckee into the divide which bounds Sierra Valley on the south. The divide is of volcanic rocks, which Lindgren regards as younger than the fault and which obscure its topographic features. No definite trace of the fault was seen about Sierra Valley, though it may cross in the vicinity of Loyalton and Beckwith, for continuing northwest beyond Sierra Valley we come to Grizzly Valley, which is in line with Indian Valley, where we find in the strong contrast of the two sides of the valley decided evidence of faulting. On the south side are the bold bluffs of Arlington Heights and Houghs Peak, which expose the ends of a thick series of sediments dipping to the southwest, while on the opposite side beyond the valley is a gentle slope, whose topographic features run beneath the north edge of the valley. The Mounds of Indian Valley are knolls which occur on a spur that runs out under the valley. The knolls are sufficiently prominent to rise above the floor of the valley. They are completely surrounded by alluvium, but clearly belong to the spur on the adjacent side of the valley and show that the deep side of the valley is on the south, under the prominent bluffs. The fault is a short one between Taylorsville and Crescent Mills and possibly around to Greenville. The amount of displacement is small. No definite trace of this fault has been found in the canyon of Indian Creek above Taylorsville, where the effects of the Taylorsville reverse fault are in evidence. The absence of the Arlington beds on the metarhyolite north of the valley, as explained on page 100, is in large measure due to pre-Jurassic erosion. The Indian Valley fault is normal, like that of Honey Lake and Mohawk Valley, and is not to be confused with the Taylorsville reverse fault of the same region.

Northwest of Indian Valley, at the lower end of Big Meadows and Mountain Meadows, the rocks of the Taylorsville region pass beneath the cover of Miocene lavas from the volcanic center about Lassen Peak. North of Prattville, along the northeast edge of Big Meadows, there is a prominent lava bluff due to faulting. Along Rock Creek and also along Warner Creek of the same region, as shown in Pl. I, similar bluffs occur, all approximately parallel and facing the southwest. They are due to faults and have been traced about a dozen miles running nearly N. 30° W. in line with the faulted belt we have traced from Lake Tahoe by way of Grizzly and Indian valleys. Continuing to the northwest, the same line passes east of Lassen Peak in the vicinity of the Snag Lake cinder cone to the prominent fault scarp known as Hat Creek Hill. It faces the southwest. The throw at the south end is over 600 feet, but it decreases to the northwest, and the fault continues for over 20 miles to near Pit River.

The faults of the Indian Valley belt in the Lassen Peak region are remarkable not only for their extent, but also from the fact that they have the downthrow on the southwest side and are of post-Miocene age.

Along Indian Valley the fault may be of about the same age, but the throw is in the opposite direction. In the vicinity of Lake Tahoe, as Lindgren has shown, there was little or no movement at the close of the Miocene. The faulting in that region occurred in the early Cretaceous, with the downthrow on the southwest, similar to that in the Lassen Peak region and the reverse of that in Indian Valley.

GEOLOGIC HISTORY OF TAYLORSVILLE REGION.

PRE-SILURIAN.

What was happening in the Sierra Nevada region during the long eons of the early geologic time is not yet fully made out. The record is fragmentary and complex. During Cambrian time it appears[a] that a mountain range may have occupied approximately the position of the Sierras and limited on the west the thick deposits of Cambrian strata laid down in the Great Basin region. Though it is known[b] that Cambrian strata extend into the Sierra Nevada west of Mono Lake, they do not outcrop in the Taylorsville region, where all the rocks are of later age.

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[a] Bull. U. S. Geol. Survey No. 208, 1903, p. 218.

[b] Bull. U. S. Geol. Survey No. 81, 1891, p. 364.

The earliest scene drawn directly from the records of the Taylorsville region is one of decided volcanic activity, during which the metarhyolite found its way to the surface, but the extent of the volcanic eruptions, whether on land or on sea, and their exact geologic date are matters of conjecture, except that they are older than the adjacent Silurian strata.

SILURIAN.

The Silurian record began over the northern end of the Sierra on the sea floor with the deposition of fine sand and occasional pebbles of the underlying metarhyolite. Layers of dark mud were formed in places containing numerous sponge spicules, such as are found in the Grizzly quartzite, to register the life of the time. Conditions changed somewhat, and corals became abundant with other forms of organisms having calcareous shells. By their accumulation local lenses of limestone were formed, whose fossils indicate the horizon of the Niagara. The occurrence of similar fossils near Eureka, Nev., suggests direct water connection with the great water body which in Silurian time occupied the central part of the United States. The general absence of this limestone on the Pacific coast except in the Taylorsville region may indicate dry land in that region during the Silurian.

DEVONIAN.

Judging from the small size of the limestone lentils, the epoch of their development was brief. Then came changes which involved elevation, exposing parts of the Grizzly quartzite to erosion, but the Taylorsville region appears to have remained much of the time beneath the sea and to have received the conglomerates, sandstones, shales, and cherts of the Taylorsville formation. The pebbles of lava contained in the fine conglomerate at the base of the formation testify to pre-Devonian volcanic activity, including such forms as the metarhyolite, a type which occurs near the same horizon in the Redding region also. The records of Devonian life are obscure or absent in the Taylorsville region, but to the northwest in the Redding region they are abundant. The sea teemed with corals, and the middle Devonian limestone of the Klamath Mountain region is locally full of them. But the record of the Devonian period in the Sierra Nevada, though much fuller than that of the Silurian, is far from complete. The Devonian period was brought to a close by an uplift which exposed the Devonian sediments locally to erosion.

CARBONIFEROUS.

The Carboniferous opened with the northern part of California beneath the sea, receiving deposits derived largely from the erosion of Devonian strata, upon which the Carboniferous strata were laid down unconformably. The shore was not far off, for many fossiliferous limestone pebbles, such as are easily destroyed, were preserved in the conglomerates of the lower Carboniferous of the Klamath Mountains. On the northern end of the Sierra the deposits were finer, composed chiefly of fine shale and sandstones, making up the Arlington formation, succeeded by the siliceous beds of Houghs Peak, with an occasional conglomerate. Then came an epoch of vigorous volcanic activity whose products are widespread. At this time the volcanic tuffs and flows of the Taylor meta-andesite were erupted, and volcanoes were active in the Sierra south of the fortieth parallel[a] as well as in the Redding region[b] of the Klamath Mountains. With the decadence of volcanic activity conditions favorable to the formation of limestone came in and heavy bodies of limestone locally full of fossils were formed throughout the Sierra and the Klamath Mountains. Toward the end of the Carboniferous volcanic action again became vigorous, resulting in the eruption of the Reeve and Kettle meta-andesites, but small lenses of limestone continued to be formed in places to the end of the period, which was brought to a close by an uplift in the Taylorsville region. This uplift in the Sierra Nevada region corresponds approximately to that of the Mississippi Valley and the eastern portion of the United States, where the Appalachian Mountains were formed and the ocean in large measure finally excluded from the Mississippi Valley. In the Sierra it appears to have been accompanied by considerable deformation and metamorphism and possibly erosion before the deposition of Triassic began, for the Paleozoic strata are decidedly more compressed and altered than those of Mesozoic age in the same region,[c] and the two are unconformable. As one of the results consequent upon the deformation of the Taylorsville region, the Taylorsville fault was formed and rhyolite was brought to the surface to receive the Triassic and Jurassic deposits laid down upon it.

TRIASSIC.

During the early Triassic the Taylorsville region appears to have been dry land, but to the northwest in the Redding region the sea prevailed, receiving upon its floor a thick deposit of lavas and tuffs interstratified with and succeeded by shales and thin sandstones of the Pit formation, which does not occur in the Taylorsville region. The northern end of the Sierra subsided, but without great deformation, at the close of Pit time, and the sea again covered a large part if not the whole of the Sierra Nevada. Coiled forms of cephalopods (ammonites) were abundant and large swimming reptiles common. Their remains spread upon the sea floor became entombed in the

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[a] Mother Lode District folio (No. 63), Geologic Atlas U. S., U. S. Geol. Survey, 1900, p. 4.

[b] Redding folio (No. 138), Geologic Atlas U. S., U. S. Geol. Survey, 1906, p. 10.

[c] Lindgren and Turner, in gold belt folios.

Hosselkus limestone. On top of the limestone the dark calcareous mud of the Swearinger slate and, in the Redding region, the Brock shale were laid down over a wide stretch along the Pacific coast from California to Alaska during an epoch which, like that of the Hosselkus limestone, was free from volcanic activity.

JURASSIC.

The Triassic was closed and the Jurassic initiated by small changes of level accompanied by a recurrence of volcanic activity, but all the while most of northern California remained beneath the sea, and the unconformity between the Triassic and the Jurassic is not great. In the Taylorsville region the earliest Jurassic deposits occur in the Trail beds of fresh or brackish water origin. These are of limited extent, for at the same time in the Redding region marine deposits were in progress. In the next succeeding epoch, when the Hardgrave sandstone was deposited, the sea covered the Taylorsville region, western Nevada, and much of eastern Oregon, which continued submerged until near the close of the Jurassic.

Though they were quiescent epochs during which the Hardgrave sandstone, Thompson limestone, and Mormon sandstone were formed, the Jurassic was a period of recurrent volcanic activity, which spread the Fant and Hull meta-andesites upon the surface and furnished a source for much of the material of which the Jurassic strata of the Taylorsville region are composed.

The fauna of the Foreman beds, which is the youngest of the Jurassic in the Taylorsville region, has not yet been studied by a paleontologist in the field, but from all that is known of it thus far its discovery has not changed the order of relative age published by Professor Hyatt,[a] in which he regards the Mariposa formation as younger than those found in the Taylorsville region.

The *Aucella* fauna in the Mariposa beds is limited in the Sierra to the lower portion of its western slope. A thick deposit of slates like those of the Mariposa has been reported by King[b] in western Nevada, but no fossils have yet been found in them to confirm the correlation. The Mariposa contains many conglomerates, and according to Lindgren[c] was laid down in "immediate proximity of the shore line." Its absence east of the main crest in the Sierra is probably due to an uplift at the close of the Taylorsville Jurassic, excluding the sea from that region. Volcanic eruptions on the west slope continued during the Mariposa.

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[a] Bull. Geol. Soc. America, vol. 5, 1894, p. 413.

[b] U. S. Geol. Explor. 40th Parallel, vol. 1, 1878, p. 395.

[c] Colfax folio (No. 66), Geologic Atlas U. S., U. S. Geol. Survey, 1900, p. 3.

EARLY CRETACEOUS (SHASTA).

The Jurassic was closed and the Cretaceous initiated by a profound compression of the rocks of the Sierra Nevada, folding and crushing them and converting the finer late Jurassic sediments, the Mariposa, into slates. In the Taylorsville region the Jurassic was completely overturned and then faulted by a later movement along the plane of the Taylorsville overthrust. The vast masses, batholiths of granitic and dioritic rocks, as well as many dikes and smaller bodies of various igneous rocks, which form so large a part of the Sierra Nevada, were intruded mainly in connection with the great compression and upbuilding of the range about the beginning of the Cretaceous, and many of the older igneous rocks and sediments were converted into schists along the borders of the batholiths.

The compression, intrusion, and uplift affected not only the region of the Sierra, but also that of the Great Basin adjoining the Sierra on the east, and at that time perhaps not yet clearly differentiated.

The whole region was above the sea and was vigorously attacked by erosion. In the course of long-continued degradation during the early Cretaceous orographic prominences were removed and the surface reduced to comparatively gentle features. A great thickness of fine deposits accumulated west of the Sierra near the fortieth parallel in the Sacramento Valley. Subsidence was in progress along the coast toward the close of the early Cretaceous, and the sea gradually encroached upon the land, but a differential change of level occurred which resulted in the formation of a thick and extensive conglomerate along the present western border of the Sacramento Valley.

This change appears to have involved the lifting up of the Sierra and Great Basin region until the latter started to collapse and break away from the Sierra by the development of a remarkable series of faults, which mark their eastern limit.

South of latitude 38° 30′ the displacement along the east face of the Sierra appears to have taken place chiefly along one fault line, but north of that latitude there were three principal lines of displacement. Beginning near Lake Tahoe they diverge slightly, and then, becoming approximately parallel, extend northwest with more or less continuity for over 100 miles. Lindgren has shown that these faults in the neighborhood of Lake Tahoe are older than the andesitic flows, and appear to have originated during the early Cretaceous. Much of the displacement occurred at that time, but north of the latitude of Sierra Valley the displacement was later.

LATER CRETACEOUS (CHICO).

During the deposition of the Chico the Sierra region was gradually subsiding and the sea transgressing until it beat upon the western foot of the mountains several hundred feet above the present level of the sea. The subsidence and transgression were greatest toward the northern end of the range, but were nowhere profound. The Chico sediments soon became fine and more or less calcareous, indicating gentle slopes upon the land approximating the condition of a peneplain.[a] The Chico closed with an uplift which excluded the sea from northern California.

EOCENE.

The uplift at the opening of the Eocene, though small, was accompanied by considerable deformation, resulting locally in a more or less distinct unconformity, but produced no striking change in the character of the marine sediments succeeding the Chico in middle California and southwestern Oregon. The valleys were deepened as a result and then widened, so that comparatively gentle slopes soon again prevailed. The landscape was one of broad and comparatively shallow valleys, whose divides preserved the gentler features of an earlier (Cretaceous) topography. The rate of disintegration became greater than that of transportation, and a mantle of residuary material rich in vein quartz accumulated upon the surface.

From the abundance of material at hand the streams became overloaded and filled their valleys. The gravels were largely quartzose and auriferous. The sand that reached the mouths of the streams was arkose. This appears to have been the condition of affairs indicated by the coaly deposits and sands which form the lower half of the main mass of auriferous gravels in the Taylorsville region.

Well toward the close of the Eocene the Sierra, in latitude 39° 30′, was elevated and greatly increased the stream grade of Jura River, flowing northward, so that it contributed gravel instead of sand to its delta, and numerous bowlders were carried into its channel. The stream grades of the western slope of the range must have been increased at the same time, but according to Turner their grade was not so great as that of Jura River. That this took place in the Eocene is suggested by the fact that the flora of this early gravel epoch is similar to that of the Eocene of Oregon.

MIOCENE AND PLIOCENE.

The conditions of gravel deposition may have continued in the Jura River region from the latter portion of the Eocene through the greater portion of the Miocene and Pliocene apparently without material change. The stream continued to flow and the estuarine body of water which it entered remained covering the north end of the Sierra throughout the period, and as far as may be judged from the gravels the river grade was not changed essentially.

Before the close of the Miocene the volcanic flows from the crest of the range began. The earliest flows were of rhyolite, which followed the lines of drainage and covered the gravels about the head of Jura River. Its eruption is represented by layers of volcanic dust in the main gravel mass on Willards Creek. These were followed after an interval by flows of andesitic and basaltic lava and breccia, which completely filled the upper course of Jura River and changed its drainage. The lower course was left uncovered, but along the Diamond Mountain region and farther northwest flows issued and covered large tracts of the main gravel mass and furnished material for the later gravels formed by the waves of the bordering water body.

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[a] Lindgren was the first to point out this peneplain (Jour. Geology, vol. 4, 1896, p. 894).

QUATERNARY.

About the close of the Pliocene great changes occurred in the north end of the range. With the adjoining portion of the Great Basin it was uplifted and afterward faulted so as to completely change its topography and drainage. The uplift increased toward the north, for the delta of Jura River was raised from a low altitude to an elevation of 7,000 feet—that is, to nearly as great an altitude as its source. The time of this deformation was subsequent to the volcanic eruptions of its vicinity but contemporaneous with great activity about Lassen Peak, as if the pressure in the one case was relieved by volcanic eruptions and in the other by upheaval.

The upheaval and deformation of the Jura River valley resulted in a complete change of drainage and added to the drainage of the watercourses of the western slope of the range, part of it going to Yuba River, but the greater portion to Middle and North forks of Feather River. The effect of the deformation upon drainage is illustrated in fig. 12 by a general profile along the Jura River bed, omitting the later effects of erosion. The ancient river bed descends from 7,000 feet

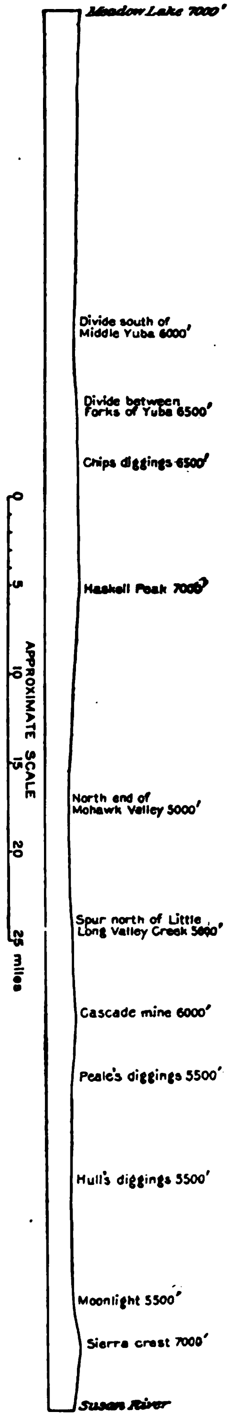


FIG. 12.—Profile of Jura River bed after deformation.

near Meadow Lake to 6,000 feet where drained by the forks of Yuba River, and rises again to 7,000 feet in Haskell Peak. Crossing Mohawk Valley fault it descends to 5,000 feet where drained by Middle Fork of Feather River, but again rises to 6,000 feet at the Cascade mine, from which there is a slight descent to Peale diggings and Moonlight drained by North Fork of Feather River. Here the gravels are decidedly lithified and arch over the eastern block of the Sierra to Susan Creek of the Great Basin region.

The deformation probably began on the east, turning the water westward, and appears to have been very gradual, permitting the forks of Feather River to maintain their courses and cut deep canyons directly across the rising crests of the range. Small temporary lakes may have been formed, but they were not extensive and were soon filled up, forming fertile valleys, of which Indian Valley is an example.

ECONOMIC GEOLOGY.

HISTORY.

During the great gold excitement in California prospectors found their way into the depths of the forest-clad mountains about Indian Valley as early as 1850. The "Bullion ledge," a short distance northwest of Greenville, was discovered the next year and many locations followed, so that within ten years Greenville became an active mining center. Gold was the primary object of search, but the discovery of rich copper ores in 1865 led to the erection of a small furnace, which maintained a sporadic activity for four years.

Though no great mines have been developed about Indian Valley, between forty and fifty small ones have at various times contributed to a total output of over $7,700,000. The values are almost wholly in gold, with a little silver and less copper. Iron ore, coal, building stone, and mineral springs, although present, have not yet become sources of revenue. There are now many active prospects in the region, but scarcely half a dozen paying mines.

On the accompanying sectional map of the Indian Valley region (Pl. V) Mr. Arthur Keddie located the surveyed mining claims of the following list in 1904, and I have added references to the prospects, mines, and ores. The claims are more or less distinctly grouped in two belts, the Crescent Mills belt and the Genesee belt.

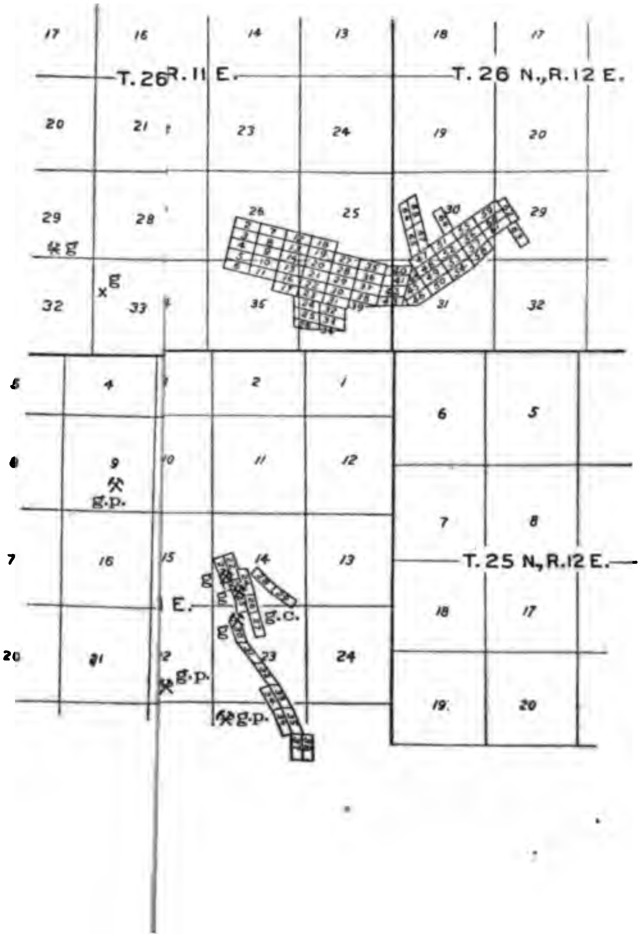
List of mining claims in Indian Valley.

T. 25 N., Rs. 9, 10, and 11 E.:

1. Bridge Q. M.
2. Shoo Fly Q. M.
3. Golden Age Q. M.
4. Golden Era Q. M.
5. Rising Sun Q. M.
6. Golden Dawn Q. M.
7. Golden Coin Q. M.
8. Greenwood Q. M.
9. Jennie Veamans Q. M.
10. Kismet Q. M.
11. Mirabile Visu Q. M.
12. Plumas Grizzly Q. M.
13. Queenie Q. M.
14. Fiesta De Oro Q. M.
15. Camp Compton Q. M.
16. Camille Q. M.
17. Hayward Q. M.
18. Rock Taylor Q. M.
19. King Solomon Annex Q. M.
20. Grand Prize Annex Q. M.
21. Genesee Q. M.
22. Italia Q. M.
23. Queen of Sheba Q. M.
24. Lodi Q. M.
25. Pilot Q. M.
26. Barney Tutt Q. M.
27. Green Ledge Q. M.
28. Queen of Genesee Q. M.
29. Copper Queen Q. M.
30. Centennial Q. M.
31. Centennial South Ex. Q. M.
32. Black Bear Q. M.
33. Brown Bear Q. M.
34. Grizzly Bear Q. M.
35. Polar Bear Q. M.
36. Cinnamon Bear Q. M.
37. Grizzly Q. M.
38. Bear Q. M.
39. Plano Q. M.
40. Peacock Q. M.
41. Ingo Q. M.
42. Copper Bell Q. M.
43. Copper Queen Q. M.
44. Morning Star Q. M.
45. Limbo Q. M.
46. Evening Star Q. M.
47. Reno Q. M.
48. Fossil Q. M.
49. Reward Q. M.
50. Beckwith Q. M.

T. 26 N., Rs. 9 and 10 E.:

1. Centennial Q. M.
2. New York P. C.
3. Kennebec Q. M.
4. Plow Boy Q. M.
5. New York Q. M.
6. Antelope Q. M.
7. Hong Kong Q. M.
8. Dewey Q. M.
9. Johnny Bull Q. M.
10. Bird Q. M.
11. Summit Q. M.
12. W. Pacific Q. M.
13. Pacific Q. M.
14. Drury Q. M.
15. Arctic Q. M.
16. Phoenix Q. M.
17. East Phoenix Q. M.
18. Sunrise Q. M.
19. Sunset Q. M.
20. Arcadian Q. M.
21. Brooklyn Q. M.
22. Comstock Q. M.
23. Dominion Q. M.
24. Union Q. M.
25. Blaine Q. M.
26. Indian Valley Q. M.
27. Arctic Q. M.
28. Summit Q. M.
29. Atlantic Q. M.
30. Hibernia Q. M.
31. Pacific Q. M.
32. Crown Point Q. M.
33. Prospect Q. M.
34. Standart Q. M.
35. Brewster Q. M.
36. Valentine Q. M.
37. Robinson Q. M.
38. Eclipse Q. M.
39. Altona Q. M.
40. Emerald Q. M.
41. Arid Q. M.
42. Lizzie Q. M.
43. Jackson Q. M.
44. Tunnel Q. M.
45. Monroe Q. M.
46. Empire Q. M.
47. Ruby Q. M.
48. Brilliant Q. M.
49. North Star Q. M.
50. Susan Jane Q. M.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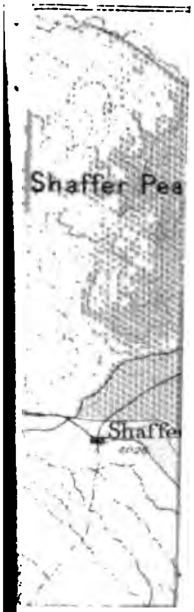
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T. 26 N., Rs. 9 and 10 E.—Continued.
51. Miller Q. M.
52. Cole Q. M.
53. Crescent Q. M.
54. Pet Q. M.
55. Plumas Q. M.
56. California No. 1 Q. M.
57. California No. 3 Q. M.
58. California No. 4 Q. M.
59. California No. 2 Q. M.
60. Palmyra Q. M.

T. 26 N., Rs. 11 and 12 E.:
1. Hull P. C.
2. Hornfel Q. M.
3. Jura Q. M.
4. Laura Q. M.
5. Lucy Q. M.
6. Omega Q. M.
7. Glass Q. M.
8. Main Q. M.
9. Wisconsin Q. M.
10. Climax Q. M.
11. Index Q. M.
12. Jupiter Q. M.
13. Mars Q. M.
14. Signal Q. M.
15. Cherokee Q. M.
16. Hopeful Q. M.
17. Gage Q. M.
18. Venus Q. M.
19. Summit Q. M.
20. Empire Q. M.
21. Locust Q. M.
22. Wonder Q. M.
23. Homestake Q. M.
24. McKinley Q. M.
25. Lincoln Q. M.
26. Garfield Q. M.
27. Queen Q. M.
28. Hammoth Q. M.
29. Williams Q. M.
30. Jessie Q. M.
31. Wide Awake Q. M.
32. Roosevelt Q. M.
33. Washington Q. M.
34. Perkins Q. M.
35. Butte Q. M.
36. Nellie Q. M.
37. Timey Q. M.
38. Rose Q. M.
39. Slim Jim Q. M.
40. Clipper Q. M.
41. Congress Q. M.

T. 26 N., Rs. 11 and 12 E.—Continued.
42. Nome Q. M.
43. Isabelle Q. M.
44. Libby Q. M.
45. Emma Q. M.
46. Molly Q. M.
47. Cooksey Q. M.
48. Chico Q. M.
49. Duncan Q. M.
50. Dome Q. M.
51. Calnan Q. M.
52. Carbonate Q. M.
53. Chondrodite Q. M.
54. Castle Q. M.
55. Jennie Q. M.
56. Cascade Q. M.
57. Cabaritic Q. M.
58. Columbine Q. M.
59. Clasper Q. M.
60. Phonolite Q. M.
61. Colorado Q. M.
62. Crown Q. M.
63. Bond Q. M.
64. Outcrop Q. M.
65. Arizona Q. M.
66. Columbia Q. M.
67. Lyddite Q. M.
68. Jeanette Q. M.
69. Bonanza Q. M.
70. Bonanza No. 2 Q. M.
71. Taylor Diggings Q. M.

T. 27 N., Rs. 10 and 11 E.:
1. Engles Copper Mine No. 3.
2. Engles Copper Mine No. 2.
3. Lucky S No. 2 Q. M.
4. Cadmus P. C.
5. Lucky S Q. M.
6. Sheep Herder Q. M.
7. Moonlight Q. M.
8. Wasp Q. M.
9. Grant Q. M.
10. Hulsman Q. M.
11. Sherman Q. M.
12. Oregon Q. M.
13. Olympia Q. M.
14. Davenport Q. M.
15. Edward Q. M.
17. Sidehill Q. M.
18. Sperm Q. M.
19. Oak Q. M.
20. Shough Q. M.
21. Gentle Annie Q. M.
22. Cabin Q. M.

T. 27 N., Rs. 10 and 11 E.—Continued.
23. Ridge Q. M.
24. No Wonder Q. M
25. Dexter Q. M.
26. Live Oak Q. M.
27. Fair View Q. M.
28. Stone Point Q. M.
29. Fritz Q. M.
30. Big Spring Q. M.
31. Big Boo Q. M.
32. Belmont Q. M.
33. Claremont Q. M.
34. Vermont Q. M.
35. Palo Cedar Q. M.

T. 27 N., Rs. 10 and 11 E.—Continued.
36. Grant Q. M.
37. Crystal Q. M.
38. Chaune Q. M.
39. Indian Valley Silver Mine.
40. Indian Valley Silver Mine.

T. 28 N., R. 11 E.:
1. North Star Q. M.
2. St. Paul Q. M.
3. Red Ocher Q. M.
4. Sunset Q. M.
5. Talbott Q. M.
6. Jackson Q. M.
7. Yellow Ocher Q. M.

DEVELOPMENT IN THE CRESCENT MILLS BELT.

The principal producing mines of the region have been the Crescent Mills, Green Mountain, Indian Valley, and McGill-Standart, all of which, with many others of less importance, lie in the Crescent Mills mining belt, which extends from the neighborhood of Taylorsville north 50° west through the Crescent Mills and Greenville districts to Wolf Creek, a distance of about 15 miles, with a width of a little over a mile. In the Crescent Mills belt in October, 1904, there were but 2 producing mines, with 1 quartz mill and 2 arrastres.

DEVELOPMENT IN THE GENESEE BELT.

The most continuous activity of the region has been along Wards Creek, on the border of Genesee Valley, where the Gruss mine has been in operation for over twenty years. Near by is the Five Bear mine, and across Genesee Valley is the Cosmopolitan, from which most of the ore was obtained years ago for the Coppertown furnace. Beyond are the Regal, Engel, and finally, in Lights Canyon, the Superior mine, where a body of bornite and chalcopyrite approximately 60 feet long, 40 feet wide, and 3 feet thick has been removed. These mines and several smaller ones lie in the Genesee mining belt, which extends from Wards Creek north 22° west to Lights Canyon, a distance of about 15 miles. While conservative estimates place the total production of the Crescent Mills belt at $6,650,000, that of the Genesee belt has been estimated at $450,000. In 1904 in the Genesee belt there were 5 mines active, with 2 stamp mills and 3 arrastres.

GEOLOGY OF CRESCENT MILLS BELT OF MINES.

The Crescent Mills mining belt has in it two long, narrow masses of granodiorite, one, southwest of Taylorsville, cutting the Paleozoic sediments; the other, between Crescent Mills and Greenville, cutting the quartz porphyries of that district. The metalliferous deposits are confined chiefly, but not wholly, to the igneous rocks, and in none of the cases examined are they definite contact deposits such as occur in a portion of the Genesee belt. The deposits throughout the Crescent Mills belt are in more or less well-defined quartz veins running generally parallel to the course of the belt, but in a few cases there are small veins nearly at right angles to the others. The ore is auriferous pyrite, sometimes in small bodies but generally disseminated in the narrow strip of sheared rock of the partially formed vein in which there is usually some quartz. The pyrite is nearly always changed to limonite, setting the gold free and staining the indistinct vein as well as its walls. One of the best defined and most complete quartz veins of the Crescent Mills belt occurs in the Premium mine. It is vertical, about 2 feet in thickness, and cuts granodiorite.

In the Green Mountain mine one subordinate vein carries a small amount of chalcopyrite, but in general copper is absent in the belt except at the old Pettinger mine, two-thirds of a mile south of Taylorsville, where a small imperfect vein in the Taylorsville slate is impregnated with carbonates of copper, sometimes blue but generally green.

An exceptional deposit for the Crescent Mills belt, and indeed for the whole region, is a mass of pyrrhotite a mile and a half nearly south of Taylorsville. It lies in a narrow strip of sheared sandstone running north and south near the horizon of the Montgomery limestone, but the largest body, about 10 feet in thickness, is at a point where the sheared sediments end against serpentine. The pyrrhotite was tested for nickel by Hillebrand, but none was found.

GEOLOGY OF THE GENESEE BELT OF MINES.

The Genesee mining belt follows approximately the northeastern limit of the Mesozoic and Paleozoic sediments where they come in contact with the granodiorite and the Kettle meta-andesite. The deposits are variable; some are more or less complete veins following narrow belts along which the rock has been crushed and sheared; others follow the line of contact bounding the granodiorite. In some deposits the ore is auriferous quartz and limonite, but in others the ore is chiefly bornite, chalcopyrite, chalcocite, or copper carbonates. Quartz is the most common gangue mineral, but in one case barite appears and in another a green mineral like actinolite.

The Gruss mine, on Wards Creek, is on both sides of the contact between the Kettle meta-andesite and slaty shale of the Robinson formation. In the shale the partially formed veins follow narrow shear zones, in which there is some auriferous quartz associated with limonite that deeply stains the richest portions of the crushed mass. The adjacent meta-andesite is often decidedly slaty and its ores are chiefly chalcopyrite or bornite, with copper carbonates near the surface.

The rocks along the contact are much sheared and apparently somewhat richer than those on either side. No characteristic contact minerals were observed to suggest that ores in this case were originally contact deposits modified after the development of the slaty cleavage.

The Five Bear mine in the Robinson slate is much like the Gruss, but the Green Ledge, Pilot, and others in the Kettle meta-andesite have small veins of quartz with bornite and some chalcocite. The veins are generally less than 5 inches in thickness.

The Cosmopolitan mine is on the contact of the granodiorite with the Hosselkus limestone and Swearinger slate. The ore is bornite and chalcopyrite, forming solid bodies up to 15 feet in thickness, with greater dimensions in the plane of contact, along which other smaller bodies of the same ore occur. On the surface the contact is marked by masses of garnet and epidote which were not seen beneath, but in the Duncan mine the garnet and epidote are associated with the ore.

The Bluebell mine is in the Hosselkus limestone near the contact, and from one of its shafts some tons of carbonate of copper have been brought up in connection with cave breccia, suggesting a secondary deposit within the limestone. A small vein of barite occurs in altered andesites at the old Indian Valley silver mine, about a mile southwest of Lucky S mine, and locally contains traces of copper ore.

Near the northwestern end of the Genesee belt is the Superior mine, in which the gangue of the bornite is a green fibrous mineral like actinolite. A number of parallel vertical veins of this mineral are well exposed in the open cut and contain disseminated particles and nodules of bornite. The larger ore bodies are free from gangue. The wall rock, which is fine-grained granodiorite, is the same on both sides and the veins are sharply defined.

AURIFEROUS GRAVELS.

Development.—In the Taylorsville region modern stream beds have been mined in Lights Canyon and on Indian Creek above Flournoy as well as below Arlington Bridge. The total yield of these modern gravels is near $10,000 annually.

About the head of Lights Creek, Mountain Meadows, and Moonlight ancient gravels have been mined irregularly in a small way for over twenty years, and the total yield, according to a conservative estimate, is nearly $500,000.

Kinds of gravel.—The auriferous gravels which have been mined about Indian Valley are of two kinds—(1) the gravels of the present stream beds and terraces near them, and (2) the gravels of ancient streams, or high gravels like those of the Taylor diggings on the mountain summits far above the streams of to-day, composed generally of well-rounded waterworn gravel.

Auriferous gravels of present streams.—The gravels of the present stream beds and their terraces have been mined at a number of points in the region, especially along the upper courses of the streams where the grade is sufficient to prevent the deposition of finer material such as fills Indian Valley proper, North Arm, and Genesee Valley.

Indian Creek heads about Diamond Mountain and Thompson Peak on the eastern crest of the Sierra Nevada in a large area of high gravels, and has doubtless concentrated whatever gold there may have been in the small amount of gravel which has been washed away. Judging, however, from present activity and recent output, the part of Indian Creek east of Genesee Valley does not hold out especially promising prospects, but this can not be taken as conclusive. The record of a greater activity years ago is not available.

Lower down on Indian Creek beyond Indian Valley, near Shoo Fly Bridge, gravel on one of the benches is worked by water taken out at the narrows and having a fall of nearly 100 feet. The excavation is but little above the stream level and has been carried on in a small way by R. Martin for a number of years. Within this portion of the quadrangle there has been no hydraulic mining for several years, but a few miles farther west, on Soda Creek, Rush Creek, and North Fork of Feather River, hydraulic and placer mining have been carried on extensively and profitably for many years.

Placer mining has been carried on along the upper course of Wolf Creek, Cooks Canyon, and several other small streams, but the most effective and persistent efforts have been made on Lights Creek and Little Grizzly Creek, just beyond the limit of the Indian Valley special quadrangle.

On Lights Creek, Ruffa, the Chatfield Brothers, and Peters work for several months every year with water under about 100 feet pressure and one or two giants each, but the amount of débris removed is small.

On Little Grizzly Creek, one of the strongest streams of the region, the work is done on a somewhat larger scale during the summer in the present stream bed, where large bowlders are encountered. In the winter the terraces from 100 to 200 feet above the stream are worked, and in the same region at a much greater elevation is the Cascade hydraulic mine described by Turner in the Downieville folio.

The entire annual yield of the placer mines within and bordering on the Indian Valley quadrangle is probably somewhat less than $10,000.

Auriferous gravels of ancient streams.—The distribution of the auriferous gravels of ancient streams in the Taylorsville region is fully shown on Pls. II and III. They are mined at a number of points, especially near the border of Moonlight, at the southeastern head of Mountain Meadows, and in Cooks Canyon, where Evans, Davis, Smith, and others have operated a month or more nearly every year for twenty years, but the work is confined to the lower edges of the gravels, which range from an altitude of 5,000 feet on the west and north to 7,000 feet at the southeast about Diamond Mountain, on the crest of the Sierra Nevada. As the gravels rest upon the summits, it is almost impossible to obtain water in quantities sufficient for ordinary mining even a few days or weeks each year.

In connection with the ancient auriferous gravels certain residual deposits should be noticed in which the débris was not waterworn nor at any time in any proper sense a part of a stream bed. The débris is simply the material derived from the disintegration of the bed rock in place. Where rocks contain veins rich in native gold, the gold liberated by disintegration lodges near by unless removed by erosion.

A third of a mile northwest of Round Valley Reservoir a placer mine on the gentle slope toward the reservoir is said upon good authority to have yielded $150,000 some years ago. The placer mine covered the northern extension of the veins from the Standart-McGill mine on the adjacent slope, and its richness is to be attributed to the residual material from the veins.

Another example of the same kind was in the placer mine of Mr. Davis, who washed the soil from the slate hill where the Gruss mine of Genesee is now located, and where auriferous veins were discovered which yielded about $25,000.

Several years ago, on the western slope of the Moonlight branch of West Fork of Lights Creek, a small but rich placer was discovered and worked for a little while. The material, though largely residual, contains some gravel and lies close to the bottom border of the great body of gravel about Moonlight. The gravel of that region rests on residual material, and it is possible that the local richness is derived from the gravels removed in the process of erosion.

DEPOSITS OF IRON ORE.

Although iron is not mined in the Indian Valley region, there are several deposits of sufficient importance to deserve mention, and at some future time they may be utilized. The most promising is at the southern border of Moonlight, in a broad valley at an elevation of 5,600 feet, 11 miles north of Taylorsville, where an area of about 2 acres occurs having red soil strewn with black chunks of hematite and with some magnetite. Some of the fragments are 2 feet in diameter. No excavations have been made, but the ore on the surface and the color of the soil indicate a considerable body of iron ore beneath.

About a third of a mile west of this locality a small opening exposes a mass of hematite, in part breccia, over 4 feet thick. It strikes nearly east and west approximately in line with the area noted above and dips about 45° to the south.

A few degrees west of south from the 2-acre area there are a number of small pits and fragments of iron ore in line to an old opening made by Hulsman, which exposes a veinlike mass of magnetite and hematite. Some of the fragments have magnetic polarity; others are not magnetic at all. The opening is only about 10 feet deep and the ore is said to run out at that depth. It is possible that there are two lines of iron-ore deposits, one nearly north and south and the other approximately at right angles. The two lines appear to meet in the 2-acre area.

Red chert is exposed at a number of points in the Indian Valley region, and it is not yet known to how many horizons it may belong. With it is always associated more or less hematite, so that the specimens frequently resemble the jasper iron ore of the famous Marquette region in Michigan.

One of the best outcrops of this kind is in the summit of Houghs Peak, but the amount of hematite exposed is always small.

An exceptional and perhaps the most interesting mineral deposit rich in iron in the Taylorsville region is the mass of pyrrhotite a mile and a half south of Taylorsville. It is briefly described on page 115, in connection with the Crescent Mills belt.

DEPOSITS OF COAL.

In the Taylor gravel diggings a few years ago a bed of coal was laid bare and at the time attracted attention. The bed is about 5 feet thick, lies nearly flat beneath the auriferous gravels to which it belongs, and rests directly upon the upturned edges of Jurassic sandstone. On the north side it is cut off by a fault and ends abruptly against the sandstone. Southward beneath the gravel its extent is unknown, but can not be great. About a ton of coal has been mined for blacksmithing, but no definite local demand has yet resulted.

Traces of coal were observed also east of Moonlight, near the base of the great deposit of auriferous gravel and sand, and mark an epoch of very gentle slope at the beginning of the auriferous gravel period. None of the coal is of economic value.

MINERAL SPRINGS.

Among the mineral resources of the Indian Valley region are several mineral springs on the main road from Taylorsville to Quincy. A few hundred yards northeast of the Arlington Bridge is an iron spring of moderately cool water containing some free carbon dioxide and carbonate of lime, so that it forms a mound of calcareous tufa deeply stained or completely covered with oxide of iron. Its flow is about 4 quarts per minute, and it is recommended by the people of the vicinity who have used it as good for those having dyspepsia.

Between Shoo Fly Bridge and Clear Creek, on the Quincy road, are two soda springs. The one near Shoo Fly is clear and cool and rich in carbonic acid, refreshing many a passing traveler; the other is less highly carbonated and has more iron. Both have deposited large masses of calcareous tufa on the steep slopes. Near the Shoo Fly Bridge the tufa looks like an ordinary limestone.

The hot spring near Greenville, said to be locally used for bathing in case of rheumatism, was not examined.

RÉSUMÉ.

The topographic elements of the north end of the Sierra are three fault blocks with prominent escarpments to the east and long, gentle slopes to valleys along their western borders.

There are eighteen sedimentary formations in the Taylorsville region, of which six are Paleozoic, nine Mesozoic, one Tertiary, and two Quaternary. The oldest is Silurian quartzite with some lentils of slate and of limestone, followed in regular order by Devonian slate and a great succession of Carboniferous strata that for convenient consideration may be separated into four formations—Arlington, Shoo Fly, Peale, and Robinson—all of which are characterized more or less fully by fossils. The first three embrace a large part of the strata which form the Calaveras of the gold belt folios.

The Triassic has two formations in the Taylorsville region, one of limestone, the other chiefly of slate, but the Pit formation and volcanic rocks at the base of the Triassic, so extensively developed in the Redding region, do not appear about Taylorsville, where their horizon is represented apparently by a marked unconformity.

The Jurassic is unconformable on the Triassic and is made up of a succession of seven formations, which are characterized for the most part by abundant faunas.

Of the igneous rocks metarhyolite is the oldest. Its effusion probably dates from early in the Silurian, certainly earlier than the time of the Grizzly formation. Volcanoes were especially active at intervals in the Carboniferous, giving rise to three extensive masses of meta-andesite. They were active also in the early Jurassic.

About the close of the Jurassic, in connection with the compression and deformation of the rocks of the Sierra Nevada, the greatest eruptive masses of the region were formed. The rocks differ markedly in type from those of earlier date. While the earlier ones were prevailingly volcanics, effusive, those at the close of the Jurassic were intrusive, some of them coarse granular, like diorite and peridotite, while others were finer grained, forming dikes.

The great structural features developed in the Taylorsville region during the orogenic epoch at the close of the Jurassic are the Grizzly

Mountains anticline, the Mount Jura syncline, and the Taylorsville fault. The Jurassic strata were completely overturned toward the east and then faulted by an overthrust—the Taylorsville fault—in the same direction.

Following the epoch of igneous intrusion and mountain building which made the Sierra Nevada a prominent range came one of long-continued erosion, for the Sierra Nevada has ever since been dry land, exposed to vigorous degradation. The earlier records of this degradation are not yet clearly made out, but the later ones are contained in the subsequent Cretaceous and Tertiary sediments of the Sacramento Valley.

Though the late Cretaceous sediments lie upon the western base of the Sierra Nevada, they do not form a considerable part of the range. The first post-Jurassic rocks involved in the main body of the northern end of the range are the earlier auriferous gravels.

The long-continued erosion during the Cretaceous, with comparatively little upheaval, reduced the bold orographic features formed at the close of the Jurassic to gentle slopes and gave rise to what Lindgren has designated the Cretaceous peneplain. A small differential uplift of the range incised the old peneplain. In the course of time the valleys were widened and filled with auriferous gravel and finally covered by volcanic flows.

The prevolcanic portion of the auriferous-gravel period is represented on the north end of the range by 1,000 feet of deposits, of which the lower half is chiefly residual sand. This sand originated in the gentle slopes of the region when disintegration exceeded transportation, and the auriferous quartz veins were set free and gradually concentrated by the removal of fine material until the rich quartz gravels of the earliest stream beds now preserved were formed. The prevolcanic portion of the auriferous-gravel period was long, and the drainage of the Taylorsville region at that time was northward, into the water body which then filled the Lassen Peak depression between the Sierra Nevada and the Klamath Mountains and received sediments of the entire period.

The flora of the early auriferous gravels of the Taylorsville region has a number of forms that occur not only in the earlier gravels of the western slope of the Sierra Nevada but also with marine shells of Eocene age in Oregon and support the suggestion made by Lindgren that the earliest prevolcanic auriferous gravels are at least in part of Eocene age.

The condition of low relief prevailed, with but slight changes of level, to the close of the Tertiary, when the Quaternary was initiated by great topographic changes, the consequences of the great uplifting and faulting of the range.

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